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NOTES FOR CHEMICAL STUDENTS.

BY

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Professor of Chemistry in the
Polytechnic Institute of Brooklyn.

SECOND EDITION.

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PREFACE.

THIS book is a rewriting of my Chemical Lecture Notes, which was published some years ago, and which has seemed to fill a gap in the literature of chemical teaching. In this rewriting a good deal has been cut out, much has been added, and all has been carefully revised.

It is not intended to be a text-book of chemistry, but to explain and supplement certain topics which experience as a teacher has shown me often give the student more or less trouble, and which are usually not sufficiently considered in the text-books. No attempt has been made to include all the difficulties that may be encountered by the chemical student. It is hoped, however, that some of the subjects considered may prove of interest and value to those students who study not merely to pass, but to know and to think.

P. T. A.

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NOTES FOR CHEMICAL STUDENTS.

CLASSIFICATION OF THE SCIENCES.

IN all attempts at classification there will occur between the various classes, tracts of No-man's Land of greater or less dimensions, and these not seldom give rise to squabbles between those who wish to rule them. The reason of this is that Nature does not deal with classes. As a matter of convenience certain properties may be selected and used as a basis of classification, but other properties may also be taken, and this will result in an entirely different classification. Thus, the chemical elements may be divided into metals and metalloids, but the distinction is not evident enough to make a clearly defined line of demarcation. The elements present a series. *We* may divide it into as many groups as we wish, but nothing very exact results. Compare the elements to the keys of a piano. It is a series of terms ascending by gradations; each member stands in certain fixed relations to every other member. Hence an immense number of schemes of classification can be worked out, but they will all be more or less imperfect. Classifications are a great convenience and an absolute necessity to the worker, but they must never be regarded as anything more than working tools. Every particle of matter in the

Cosmos stands in some sort of a relation to every other particle of matter in the Cosmos; that is, its relations are infinity. Any attempt, therefore, at strict classification will be a failure. The same holds in many other branches of knowledge. The more perfect a classification seems to be, the more limited is one's knowledge and the narrower one's mind. In the same way, a definition is the expression of certain facts in the terms of certain other facts. It is a statement of relations. As each fact is related in some way to all other facts, it is easy to see how a few adroitly put questions will shift the consideration of a subject from one field to another. It is also evident that all knowledge must be relative and imperfect, since each term is related to every other term, and the number of these terms is infinity. As we can know but a limited number of these terms, and still fewer of their relations, our knowledge must be correspondingly limited. As one studies and thinks more deeply, relations will be discerned between things which at first appeared to be entirely independent of each other. A good test of the powers of investigation and the state of knowledge is to try to work out relations between widely differing facts. The sciences run into each other. Chemistry and physics are distinguishable for a time, but soon a field is reached that belongs to both. An illustration will make this plainer. Suppose certain sciences to be represented by the fingers. They are clearly distinguishable at first, but soon gradually merge into the hand—the parent science—and the hand into the arm. So the arms and legs merge into the trunk. All of these ramifications concentrate and finish at the capital, or seat of government, which is called the brain. Now a finger is not a hand, nor is a hand a hand if the fingers are removed, and so on. It is evident that to classify the fingers we must refer to the hand. The hand implies an arm, an arm a trunk, a trunk a head, and so on. While the idea that classification is an expression of limited knowledge should be kept clearly before us, the value of classification, not alone as a most powerful factor in all kinds of investigation, but as a means of intellectual drill, must not be for a moment belittled or neglected.

VOLUME RELATIONS.

As* the current passes from one platinum pole to the other in a Hofmann electrolytic apparatus filled with water, a stream of bubbles arises from each. One stream is more energetic than the other, and, in a short time, there is in one tube twice the volume of gas that is in the other. Water, then, by the action of the electric current, breaks into two gases. The gas must come from the water, for there is no other source. The gas produced in the larger amount is the element hydrogen, while the other is the element oxygen.

Water has been by this experiment resolved into two gases, hydrogen and oxygen. But does water contain any other substance? As all of the water in the apparatus has not been decomposed, it could be argued that there might be other substances, not gases, which were set free and remained dissolved in the undecomposed water. To determine this, there are mixed in a proper apparatus oxygen and hydrogen, in the proportions in which they are liberated from water, *i.e.*, one volume of oxygen and two volumes of hydrogen, and the mixture is fired by means of an electric spark. There is a slight explosion, a flash of flame, the gases vanish, the mercury rises, and the sides of the tube are bedewed with moisture, which was not there before. It came from the explosion of the two gases. It is therefore proved that water is composed—is a *compound*—of two gases, oxygen and hydrogen; and further, that it is composed of two volumes of hydrogen and one volume of oxygen. The proof was perfect; *analytical* when the water was split into two gases, and *synthetical* when the gases recombined to form water.

---

* This explanation is essentially that given in Hofmann's "Einleitung in die moderne Chemie."

It is necessary, now, to find out the relations between the amounts of the gases and of water. How many volumes of water, or rather steam, since the volume of the constituent gases cannot be compared with the volumes of liquid water—how many volumes of steam will one volume of oxygen and two volumes of hydrogen form after explosion? It might be supposed that one volume of oxygen and two volumes of hydrogen would form three volumes of steam, or water-gas. Two volumes of hydrogen and one of oxygen are mixed in a tube provided with a steam-jacket, so that the water formed by the union of the gases will not condense to a liquid, but remain as water-gas, or steam. On comparing the volume of the steam with the volume of the gases from which it has been formed, it is found that there has been a diminution in volume. Three volumes have contracted to two. Hence by the combination of

1 volume of oxygen with
2 volumes of hydrogen
2 volumes of steam are formed.

Is this a general law? Does this relation exist between all substances? To investigate this let some other substances be examined. A strong aqueous solution of hydrochloric acid when submitted to the action of the current in an apparatus similar in principle to the one used for water evolves two gases. Allowing them to collect in their respective tubes, it is found that the gases are evolved in equal amounts. The one that is colorless burns with a non-luminous blue flame. It is hydrogen. The other does not burn and does not support combustion. It has a greenish yellow color and a suffocating odor. It is the substance known as chlorin. By exploding a mixture of equal volumes of chlorin and hydrogen, hydrochloric acid gas is at once reformed, but there is no change in the volume of the gases. The proof of combination is in this case also perfect, being both analytic and synthetic. Hence by the combination of

1 volume of hydrogen with
1 volume of chlorin
2 volumes of hydrochloric acid gas are formed.

There is another substance well known under the name of ammonia, or hartshorn. When an aqueous solution of this gas is submitted to the action of the electric current, in an apparatus similar to the one used in the preceding experiment, the ammonia is decomposed and two gases are obtained in the proportion of one volume of one to three volumes of the other. Both of the gases are colorless, tasteless, and inodorous. The one of which there is the greater amount burns with a blue, non-luminous flame, and is at once recognized as hydrogen. The other does not burn and does not support combustion. It is the gas known as nitrogen. Hydrogen and nitrogen do not easily recombine directly, so that a synthesis, such as was effected in the preceding cases, is not possible. As it might be inferred from analogy, however, that should a synthesis of ammonia gas be made, two volumes of it would be formed, an experiment can be made to ascertain if the analogy holds good analytically. In a tube marked with four equal divisions, two volumes of ammonia gas are decomposed by the electric spark. When the decomposition is complete, the volume of the resulting mixture of hydrogen and nitrogen is twice that of the original volume. In other words, two volumes of ammonia gas produce four values of a mixture of hydrogen and nitrogen. By the first experiment it was proved that this gas mixture consists of three volumes of hydrogen and one of nitrogen. Therefore it is now proved that

1 volume of nitrogen and
3 volumes of hydrogen are formed from
2 volumes of ammonia gas.

As these results may be read either way, they may be expressed synthetically:

By the combination of

1 volume of nitrogen with
3 volumes of hydrogen
2 volumes of ammonia gas are formed.

Tabulating the results of the three experiments:

1 vol. of H and 1 vol. of Cl gave 2 vols. of HCl.
2 vols. of H and 1 vol. of O gave 2 vols. of H_2O.
3 vols. of H and 1 vol. of N gave 2 vols. of NH_3.

It appears from these experiments that no matter what is the sum of the constituent gases, the volumes of the gases formed will be equal to two, the smallest constituent volume being taken as one. There are some apparent exceptions to this rule which will be considered later on.

WEIGHT RELATIONS.

In the foregoing, one very important matter has been left unconsidered, *i.e.*, the *weight* of the substances; only their volumes have been mentioned. As there is no such thing as an absolute weight, the weights of gases are referred for convenience to the weight of a certain volume of the lightest one known, which is hydrogen; *i.e.*, the weight of a certain volume of hydrogen is taken as a unit in the estimation of the weights of gases.

A liter of hydrogen at 0° C. and 760^{mm} weighs 0.0896 grams. This weight is much used in chemical measurements, and is called the "Crith," the word being derived from the Greek and meaning a barleycorn.[*] A liter of oxygen weighs 1.43 grams, and hence is 16 times heavier than hydrogen. Or we can say that it weighs 16 criths. A liter of chlorin weighs 35.5 times as much as a liter of hydrogen, a liter of nitrogen 14, and so on. This weight of a gas expressed in criths, that is, in hydrogen units, is called its specific gravity, volume-weight, or *density*. Thus the density of $O = 16$, of $N = 14$, of $Cl = 35.5$. In other words, a certain volume of chlorin, for instance, weighs 35.5 times as much as an equal volume of hydrogen. But one volume of H[†]—say one liter—unites with one volume of Cl, or, in this case, with one liter of Cl. Hence one part by weight of H unites with 35.5 parts by weight of Cl.

1 liter of	H,	1	part by weight.
1 "	Cl,	35.5	" "
2 liters of	HCl,	36.5	parts by weight.

---

[*] It is well for the student to satisfy himself that he really understands what is meant by the weight of a body. What is "weight"? A review should be made of the metric system. Instead of weight, the word "mass" is now used. "Mass is the one property of matter which remains absolutely constant in every state of chemical combination." (Cornish.) Weight is a measure of mass. See Barker's Chemistry, and Gage's Physics.

[†] The symbols instead of the names of the elements are here used intentionally.

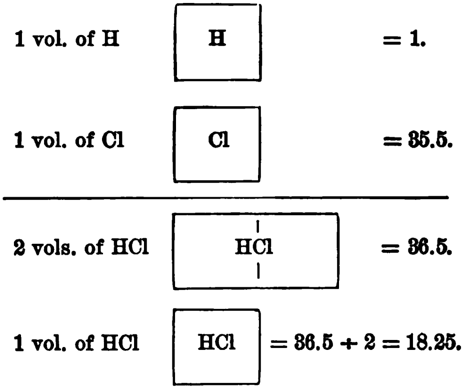
The weight of the hydrochloric acid formed is, then, 36.5. More accurately:

1 liter of H weighs 0.0896 grams.
1 " Cl " 3.1808 "

---

2 liters of HCl weigh 3.2704 grams.

But the amount of HCl formed from one volume of H and one volume of Cl is equal to two volumes, since one volume of H and one volume of Cl yield two volumes of HCl. To compare, then, the weight of *one* volume of HCl gas with one volume of H, the volume-weight of the HCl must be divided by 2.



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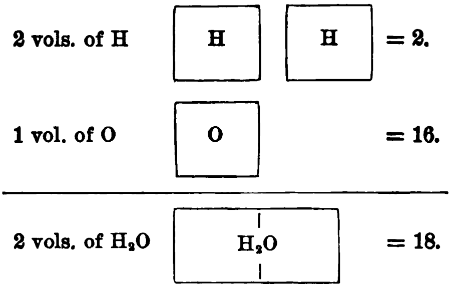

$$\begin{array}{llllll}
1\text{ vol. of } H_2O & \boxed{H_2O} & & & = 18 \div 2 & = 9.
\end{array}$$

Lastly:

$$\begin{array}{llllll}
3\text{ vols. of } H & \boxed{H} & \boxed{H} & \boxed{H} & & = 3. \\
1\text{ vol. of } N & \boxed{N} & & & & = 14. \\
\hline
2\text{ vols. of } NH_3 & \boxed{\quad NH_3 \quad} & & & & = 17. \\
1\text{ vol. of } NH_3 & \boxed{NH_3} & & & = 17 \div 2 & = 8.5.
\end{array}$$

The specific gravity of a substance in the gaseous state, referred to hydrogen as unity (*i.e.*, its density), is equal to half the sum of the weight of its constituent elements.

Representing one volume, or one part by weight, of hydrogen by the symbol H, and one volume, or 35.5 parts by weight, of chlorin by Cl, the formula of hydrochloric acid is written HCl. This means that one volume, or one part by weight, of hydrogen is united to one volume, or 35.5 parts by weight, of chlorin. Hence the formulas HCl, H_2O, and NH_3 show not only of what substances and how many volumes of each substance the compound consists, but also that the compound, when in the state of gas, occupies the space of two volumes, if it is assumed that by the symbol H one volume of hydrogen is meant. These formulas show further that in hydrochloric acid, HCl, to 1 part by weight of hydrogen 35.5 parts by weight of chlorin are contained; in water, H_2O, that to 2 parts by weight of hydrogen there are contained 16 parts by weight of oxygen. And lastly, in ammonia, NH_3, there are 14 parts by weight of nitrogen to 3 parts by weight of hydrogen. A chemical formula has, therefore, a great importance, and presents a remarkable review and summary. These formulas express:

1. Of what elementary substances the compound is composed.
2. How many volumes of each element have taken part in the formation of the compound.
3. How great the weight of the compound is, assuming $H = 1$.
4. The volume-weight, or density, of the compound in the gaseous state, which, as has been explained, is just half the weight of the compound.

It is also to be observed that the weights of the various volumes of gases are at the same time the weights with which the substances enter into combination. They are hence often called the *Combining Weights*.

The combining weight of $H = 1.$
" " $Cl = 35.5.$
" " $O = 16.$
" " $N = 14.$

The experiments show also that only one volume of hydrogen and one volume of chlorin, or, in other words, one part by weight of hydrogen and 35.5 parts by weight of chlorin combine to form hydrochloric acid. It might be argued, however, that, while this relation of combination is undoubtedly correct, others might exist. To investigate this, varying mixtures of hydrogen and oxygen are mixed in a suitable apparatus and exploded. For instance, in No. 1 there is placed a mixture of 1 vol. of oxygen and 2½ vols. of hydrogen. In No. 2, 1¼ vols. of oxygen and 2 of hydrogen. On exploding the mixture by means of an electric spark, water is formed in each case, but in No. 1 half a volume of hydrogen is left over, and in No. 2 one quarter of a volume of oxygen. So, also, if a mixture of 1 gram of hydrogen and 36 grams of chlorin is exploded, 36.5 grams of hydrochloric acid are formed, and 0.5 gram of chlorin will be left over. It is therefore proved that exactly one part by weight of hydrogen, and not 1½, 1¾, etc., unites with exactly 35.5 parts by weight of chlorin, and not 36 or any other amount. Absolutely fixed relations exist between the amount of chlorin and the amount of hydrogen that combine to form hydrochloric acid, between hydrogen and oxygen in forming water, and between nitrogen and hydrogen in forming ammonia. The quantities in which the various elements unite to form a given compound are not arbitrary, but absolutely fixed. This is called the *Law of Combination in Definite and Constant Proportions.* It was discovered by Dalton.

We are now in a position to deduce the great principle on which chemistry and all physical science rests. It has been proved that

1 part by weight of hydrogen and
35.5 parts by weight of chlorin yield
36.5 parts by weight of hydrochloric acid.

And

2 parts by weight of hydrogen and
16 parts by weight of oxygen yield
18 parts by weight of water.

And

3 parts by weight of hydrogen and
14 parts by weight of nitrogen yield
17 parts by weight of ammonia.

It has also been proved that

From 36.5 parts by weight of hydrochloric acid
There are formed 35.5 parts by weight of chlorin
And 1 part by weight of hydrogen.

And from 18 parts by weight of water
There are formed 16 parts by weight of oxygen
And 2 parts by weight of hydrogen.

And from 17 parts by weight of ammonia
There are formed 14 parts by weight of nitrogen
And 3 parts by weight of hydrogen.

A great number of similar examples could be cited. From the above it follows that the weight of each compound is equal to the sum of the weights of its constituents; and, secondly, that the sum of the weights of the various constituents obtained from a compound is equal to the weight of the compound taken. In other words, in all changes that matter may suffer, none of it is lost. This is the basic principle known as the *Indestructibility of Matter*. It is to be observed that in establishing this law it was necessary to obtain a synthetic as well as an analytic proof. This principle is now usually called *The Conservation of Mass*, and is defined by Ostwald: "The total mass of the substances taking part in any chemical process remains constant."

MOLECULES.

By careful grinding and rubbing, it is possible to divide a solid into very small particles. Thus ice can be ground and pulverized until it is an impalpable powder, and yet no one would doubt that each of these extremely minute particles of ice is still solid water; and, had we the means to examine such a minute speck, it could be proved to be solid water. By warming a quantity of this pulverized ice, it melts, and water is formed, which may again be frozen and comminuted. This is a sufficiently good proof that, no matter how fine we powder the ice, it does not cease to be ice.

The above example is a good introduction to the views which chemists hold as regards the subdivision of matter. It might be imagined that, had we the means, the subdivision of these little pieces of ice could go on forever. Chemists, however, do not consider matter to be infinitely divisible. There is reason to think that when a mass of matter is subdivided into smaller parts a limit is finally reached beyond which farther subdivision, without decomposition and destruction of the characteristic nature of the matter, is impossible. Thus a point would be arrived at when the particle of ice, even though extremely minute, might still be divisible, yet could it be divided, the divided particles would not be ice. One must be careful to keep the metaphysical and chemical ideas separate. The metaphysical deals with space as an abstract consideration. The first property of space is divisibility. No matter how small a body is, it must occupy a certain space, and hence is capable of division. With this the chemist has nothing to do. He simply affirms that the divisibility of matter, so far as concerns the individuality of the particular kind of matter dealt with, is not unlimited, but definitely fixed. Should it be found possible to divide one of these concrete particles, another, perhaps new, form of matter would be obtained, and it would be the duty of the chemist to examine it. Infinite division of matter is, then, a metaphysical speculation, based on the study of the space that the matter fills. Finite division is an inference based on experimental evidence furnished by physical science.

These small particles, when existing in a free state,* are called molecules (from *molecula*, the diminutive of *moles*, a mass). It is further supposed that these molecules do not lie close to each other, but are separated by intervening spaces, and in gases these intervening spaces are so great in comparison to the size of the molecules that the size of the latter is almost nothing when compared to the intervening space. We are naturally unable, by any mechanical means at our disposal, to subdivide matter down to the single molecule. The finest particle that can be obtained by pulverization would appear under a microscope as a large lump, and would still contain myriads of molecules. The particles in these lumps are capable of still further separation. Suppose, for instance, ice be rubbed to an impalpable powder. There will be a considerable air-space between each of the specks of ice, and each particle of ice will contain myriads of molecules. Now let this ice-powder be heated until it turns into steam. As ice expands 1500 times its volume in passing into steam, it is evident that each of the specks of ice will occupy as steam a space 1500 times greater than its original volume. But the number of molecules is not altered. Hence, while the molecules are far apart in ice, they must still be further apart in steam. It is not difficult to understand that the most refined methods of mechanical measurement are as yet of but little use to us in attempting molecular measurements.

All gases increase in volume when they are heated, or when the pressure on them is diminished, and decrease in volume when they are cooled, or when the pressure on them is increased. This change in the volume of a gas from alteration in the pressure or temperature is the same in all gases. All gases expand or contract equally when the temperature or pressure is increased or diminished equally. It has been found that every gas on being heated 1° C. expands $\frac{1}{273}$ of its volume at 0°. 273 c.c. of a gas at 0° would, on being heated to 1° C., become 274 c.c. By cooling one degree it would contract $\frac{1}{273}$.

---

* This will be explained later on.

273 c.c. at 0°.
274 c.c. " 1°.
272 c.c. " – 1°.

No particular gas is mentioned, because all *true* gases behave in this way. By true gas is meant a *gas* as distinct from a vapor. A vapor is formed when a gas is more or less condensed. As steam issues from a jet, it is an invisible gas, but it soon condenses more or less into minute globules of water, and is then a vapor. A vapor is generally a mixture of gas and a liquid, or, in some cases, also of a solid.

If the pressure in a gas is doubled, its volume will be decreased one-half; or if the pressure is decreased one-half, its volume will double. All these changes in the volume of gases must be the result of an increase or decrease in the spaces between the molecules. The simplest explanation of these changes in the volumes of gases is that at equal temperature and equal pressure the spaces between the molecules are equal. Or, in other words, as the intermolecular spaces are so much greater than the molecules themselves, the law may be expressed more simply as follows: Equal volumes of gases measured at the same temperature, and under the same pressure, contain an equal number of molecules. This is known as the "Law of Avogadro," sometimes, also, of "Ampere."* It forms the foundation on which Theoretical Chemistry rests, and explains chemical and physical phenomena in a remarkably satisfactory way. Its discovery has opened up unlimited fields for investigation in physical science.

---

* Avogadro seems to have been the first to discover it.

Another property of these molecules, that is wonderfully interesting, is their motions. Air consists of a mechanical mixture of oxygen and nitrogen gases. As the former is the heavier, why does not air separate into two layers? Fill a jar half full of heavy carbonic acid gas and fill up the remainder of the space with oxygen gas, which is a much lighter gas and hence forms a layer resting on the heavy gas. Let them stand undisturbed, and before long the gases will have mixed as perfectly as if they had been stirred. Let a layer of alcohol swim on the surface of water, and after a time they will have commingled, although not agitated. Into a jar of a cubic foot capacity, out of which the air has been exhausted, let in a cubic inch of air, and this cubic inch will expand to fill the whole cubic foot. Place a rubber bag half full of air under the receiver of an air-pump. As soon as the air is exhausted the bag swells up and, perhaps, explodes.

It has been stated that a gas does not consist, as one might perhaps suppose, of a very thin continuous form of matter, but of small particles called molecules, or little masses. These particles move with great rapidity in straight lines. They are perfectly elastic, and, when a particle strikes a surface, it bounds back and continues its path until it again collides. Imagine what is taking place in a jar filled with air. Myriads of these minute particles are showering against the sides, bounding back, striking each other, colliding in all directions in ceaseless activity. The sides of the jar are exposed to a continual molecular bombardment. Think of this going on about us now—the ceaseless hail of the molecules against us! And yet we neither hear nor see them. Imagine the power of vision increased many billions of times and see in your mind's eye the room filled with flying cannon-balls, colliding, glancing, rebounding, always moving, restless, tireless, never-ending motion. A cubic inch of air will afford calculations enough for a generation of chemists, physicists, and mathematicians. Now it is clear why the cubic inch of air filled the empty space. The molecules flew in all directions in straight lines until the walls stopped them. Why the rubber bag swelled up when the pressure of air was taken off it. Its surface was stretched by blows from the billions of little bullets within it. Why two gases mix without aid. How could they avoid mixing, when each is but a multitude of molecules flying in all directions? How could air separate into its constituent gases, oxygen and nitrogen, when every particle is imbued with ceaseless motion?

Suppose that a gas is placed in a cylinder and a pressure of ten pounds is applied to it by means of a piston. The gas contracts a certain amount in volume, the result of the compression. When a gas is compressed what takes place? Why, the blows of the molecules on the bottom of the piston are overcome. Soon the piston, with its load of ten pounds, ceases to sink. It rests on the gas within and is supported by it. The united impacts of the molecular bombardment within the cylinder now equal the pressure of ten pounds that has been applied to the piston. The more the volume of the gas is diminished by pressure the greater must be the number of blows struck by the particles in a given space of time. What could be simpler? But equal volumes of all gases, at the same temperature and under the same pressure, suffer the same amount of compression by this weight of ten pounds. Then each gas must exert the same resistance to the piston. But the resistance is merely the sum of all the blows struck by the molecules of the gas opposing the pressure of the piston. Then, since there is the same number of molecules in each equal gaseous volume, each molecule in this gas, no matter whether it is oxygen, hydrogen, or nitrogen, or any other, must strike the same blow. But, it might be argued, a cubic foot of hydrogen is very much lighter than a cubic foot of oxygen. Then, if a cubic foot of hydrogen and a cubic foot of oxygen each contain the same number of molecules, and the pressure of the gas is simply the sum of the blows or impacts of the molecules, how can the two gases exert the same pressure? How can a million very light molecules of hydrogen produce the same bombardment-effect as a million heavy molecules of oxygen? It would be much more pleasant to be struck by balls of cork than by balls of lead. Here mechanics comes to our aid. The velocity of the molecules must be taken into acount. The light molecule of hydrogen gives the same blow that the heavy molecule of oxygen does, but to do this it has to move at a much greater speed than the molecule of oxygen.

So we see that these invisible gases consist of myriads of molecules moving in straight lines, bombarding all obstacles placed in their way, each molecule striking the same blow.* The effect of heat is to increase the rapidity of the motion of the molecules, and hence each one strikes a heavier blow, and so pressure is produced on heating a gas in an enclosed space, or equal expansion for every increment of heat. The pressure in a steam-boiler is the constant striking of the molecules of steam against its interior. Fancy what a battering the piston of a large engine must get to make it twirl its fly-wheel! Listen to the bustle and hum of a large factory, and realize what *work* these active little molecules are doing all the time. Think of the tremendous energy continually active in the air about us. In the warm sunlight, hemmed by the fleecy clouds and fanned by the gentle breeze which hardly makes the leaves quiver, with the tinted landscape stretching out in its peaceful quiet, it is hard to realize that this space is filled with madly racing hordes of molecules, a vast hurricane of energizing dust.

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* To be more exact, it should be said that the total impact of each molecule in a unit of time is the same, for there are many internal collisions, and variations in molecular speed,

The mind soon ceases to follow the infinite number of complicated motions that these swarms of molecules assume. It has been calculated that, at the temperature of freezing water, the molecules of hydrogen must move 5571 feet a second and must suffer 10,040,000,000 collisions in a second. That is, the direction of the motion of a hydrogen molecule must be changed 10,040,000,000 times in a second. In a cubic inch of hydrogen it is estimated that there are 110 quintillions of molecules (110 with 18 ciphers after it), and each of these particles changes its direction about 10,040,000,000 times in a second. Even then, however, the space is by no means full, for the molecule has an average free space to move in between the collisions of about 67 millionths of an inch. The molecules themselves are, as far as we can estimate, 0.000,000,019 of an inch in diameter. The weight of a molecule of hydrogen has been estimated to be 0.000,000,000,000,000,000,000,004 gram. (Risteen.)

In the case of liquids the motions of the molecules seem to have become more sluggish and no longer in approximation to straight lines, but in paths more or less elliptical. Water is, then, not a continuous liquid, or fluid, but a mass of particles travelling about, striking the sides of the vessel and continually colliding. Magnify a drop of water one eighth of an inch in diameter to the size of the earth and the molecules will appear larger than coarse shot and smaller than baseballs. What a complexity of motions there must be in a drop of water; our solar system is nothing to it. It is now possible to understand why liquids mix without stirring, for the molecules cannot avoid getting inextricably entangled in their continual revolutions. The clear, smooth surface of water that stretches far away to the dim horizon, could the power of the eye be increased, would look like a vast cauldron filled with swarms of flies. As the temperature of a gas is reduced the velocities of its molecules become more and more sluggish, till at last they cease to move in straight lines but follow more or less elliptical paths and crowd more closely together, or, in other words, it becomes a liquid. If a liquid is heated, the paths of the molecules become in time straight lines, and the liquid turns to gas, as, for instance, water into steam. Even at ordinary temperatures now and then some particle, more daring than the rest, will escape from its companions near the surface and travel off into space. This is what is called evaporation. Picture what a turmoil there must be as the air showers its molecules against the revolving molecules of an aqueous surface!

Steam, a gas, consists of molecules moving in straight lines, water, of molecules moving in more or less elliptical paths. In ice, the solid water, the paths of the molecules are more or less circular, or, perhaps, the molecules are simply in vibration, or oscillation. It is seen at once why solids do not mix of themselves. It may seem well-nigh absurd to think of houses, books, chairs, and ourselves, for the matter of that, all consisting of little specks of matter in constant motion, yet so the scientific man regards them.

How is it possible, one might ask, for a piece of rock, which has lain for years in some spot, to be composed of oscillating particles, and yet appear so stationary? On a summer's afternoon it is not unusual to see a swarm of gnats, which at a distance looks like a small stationary cloud. At times the cloud moves about. When one approaches it, however, it is found to be composed of myriads of these minute insects flying about in all directions, and yet, at a little distance, it appears as a cloud whose outlines are clearly defined. In the woods a large black ball is sometimes seen hanging to the limb of a tree. It appears motionless, but on a closer examination is found to consist of a swarm of bees, climbing over each other in ceaseless motion. So, a mass of men, all of whom are actively moving, appears at a little distance as a stationary black spot. It is not difficult, therefore, to understand how a mass of matter can consist of innumerable moving particles and yet appear motionless. Could any solid—stones, steel, diamonds, wood—be magnified sufficiently, its *grained* structure would become apparent.

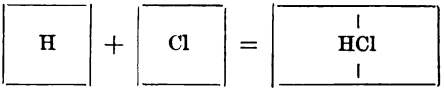
Those who are interested in the study of matter —and how can one fail to be when one has once begun it ?—will find the following references worth looking up: Recent Advances in Physical Science, Tait; Properties of Matter, Tait; Matter and Motion, Clerk-Maxwell; Encyc. Britannica and Watt's Dictionary of Chemistry, article "Atom"; Matter, Ether, and Motion, Dolbear; Molecules and the Molecular Theory, Risteen. The study of matter surpasses in its extraordinary nature the most remarkable works of fiction.

MOLECULAR WEIGHTS.

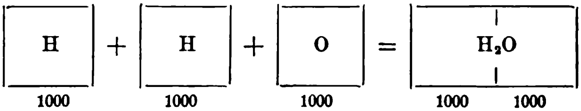
Although a molecule occupies an extremely minute space, it still occupies space, and hence must have a weight, even though this weight is immeasurably small. These weights of molecules must also stand in some sort of relation to each other, and these relations of weights of molecules are called the relative weights of the molecules. Suppose, for instance, that a liter of hydrogen contains 1000 molecules. Then, according to the law of Avògadro, a liter of chlorin, of oxygen, and of nitrogen will also each contain 1000 molecules, the pressure and temperature in each case being the same. A liter of chlorin, however, weighs 35.5 times as much as a liter of hydrogen. Hence $\frac{1}{1000}$ of a liter of chlorin must weigh 35.5 times as much as $\frac{1}{1000}$ of a liter of hydrogen. But $\frac{1}{1000}$ of a liter of chlorin is a molecule of chlorin, and $\frac{1}{1000}$ of a liter of hydrogen is a molecule of hydrogen. Hence a molecule of chlorin is 35.5 times as heavy as a molecule of hydrogen. Therefore the weights of the molecules, *i.e.*, the *molecular weights*, are to each other as the weights of equal volumes of the gaseous substances when weighed under the same conditions of pressure and temperature.

ATOMS.

Suppose that a liter of chlorin is allowed to combine with a liter of hydrogen to form hydrochloric acid. Two liters of hydrochloric acid gas are formed:



If we assume that the liter of chlorin contains 1000 molecules, then, according to the law of Avogadro, the liter of hydrogen must also contain 1000 molecules. Since one liter of hydrogen and one liter of chlorin give two liters of hydrochloric acid gas, and one liter of hydrogen contains 1000 molecules, and one liter of chlorin also contains 1000 molecules, each volume of the hydrochloric acid gas must contain 1000 molecules, or, as there are two volumes of hydrochloric acid gas, there must be in all 2000 molecules of hydrochloric acid formed. But each molecule of muriatic acid consists of hydrogen and chlorin, consequently in the 2000 molecules of hydrochloric acid there must be 2000 constituent particles of hydrogen and 2000 constituent particles of chlorin. Since there have been used for the production of these 2000 molecules of hydrochloric acid 1000 molecules of hydrogen and 1000 molecules of chlorin, it follows that each molecule of hydrogen and each molecule of chlorin must consist of two still smaller constituent particles which are combined in the same way as the hydrogen and chlorin in hydrochloric acid. In the same manner, 2 liters of hydrogen (2000 mols.) and 1 liter of oxygen (1000 mols.) form 2 liters of steam (2000 mols.):



But in each of these 2000 molecules of steam there must be a particle of oxygen. Hence each of the 1000 molecules of oxygen must contain two still smaller particles.

These smaller constituent particles of which the molecule is composed are called *atoms*. As a rule, they do not exist in the free state. Each molecule of muriatic acid contains one atom of hydrogen and one atom of chlorin. A molecule of water contains two atoms of hydrogen and one atom of oxygen. A molecule of ammonia contains three atoms of hydrogen and one atom of nitrogen. In the same manner, each molecule of hydrogen consists of two atoms of hydrogen, each molecule of chlorin of two atoms of chlorin, and so on. The attraction that binds the atoms together to form a molecule is called *chemism*.

When the molecules of a substance are composed of atoms of the same kind, it is called an *element*. If the molecules of the substance are composed of dissimilar atoms, it is a *compound*.

It is therefore to be concluded that—

1. The molecule is the smallest particle of matter, either simple or compound, that can exist in the free state; *i.e.*, into which a substance can be divided without losing its identity.

2. The molecules themselves consist of still smaller elementary particles, called atoms, into which they cannot be resolved without combining among themselves (the atoms) in a different order, and thereby giving rise to new bodies possessed of new properties.

3. A molecule fills two volumes when it is assumed that an atom of hydrogen fills one.

4. The chemical formula of a compound represents a molecule of it.

5. The chemical symbol of an element represents an atom of it.

6. The combining weights of the elements are their atomic weights.*

These statements refer more particularly to gases. Our knowledge as to the molecular and atomic state of liquids and solids is not so exact. At high temperatures a gas may consist of free atoms.

It is as difficult to form an idea of the real minuteness of the atom as it is to grasp the vastness of astronomical distances. The following illustration may help: The mechanical subdivision of matter can sometimes be carried very far. A single grain of gold can be hammered out so as to cover 49 square inches. Each square inch can be cut into 100 strips, and each strip into 100 pieces each of which will be visible to the unaided eye. A single grain of gold can thus be subdivided into 490,000 visible pieces. Another inch can be attached to a glass plate and 10,000 lines ruled on it.

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* I have followed here quite closely the text of Pinner's Repetitorium der anorganischen Chemie.

This will give 100,000,000 pieces; or the entire grain of gold can be so divided into 4,900,000,000 pieces, and each is visible through a microscope. Each piece would be less than 1,103,000,000 of an inch. Each of these pieces, however, could still be a mass of matter, and contain myriads of molecules, not to speak of the number of atoms.

Molecules may be defined as *the smallest particles of matter that can exist in the free state;* or as *the smallest weight of matter in which the original properties of the matter are retained.* Atoms may be defined as *the smallest particles of matter that can take part in a chemical change.* (Newth.) See further under Atomicity.

COMBINATION IN DEFINITE PROPORTIONS.

DEDUCED FROM ANALYSIS.*

Analysis of chemical substances prove that the elements unite with each other in definite or constant proportions, but the percentage composition afforded by analysis does not at first glance show that the elements unite with each other in simple proportions.

CHLORIDS.

Hydrogen Chlorid.	
Chlorin	97.25%
Hydrogen	2.75%
	100.00%

Potassium Chlorid.	
Chlorin	47.53%
Potassium	52 47%
	100.00%

Sodium Chlorid.	
Chlorin	60.61%
Sodium	39.39%
	100.00%

Silver Chlorid.	
Chlorin	24.73%
Silver	75.27%
	100.00%

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* The matter of this and the following paragraph is taken from Roscoe and Schorlemmer's Chemistry.

BROMIDS.

Hydrogen Bromid.		*Potassium Bromid.*	
Bromin	98.76%	Bromin	67.13%
Hydrogen	1.24%	Potassium	32.87%
	100.00%		100.00%

Sodium Bromid.		*Silver Bromid.*	
Bromin	77.62%	Bromin	42.55%
Sodium	22.38%	Silver	57.45%
	100.00%		100.00%

IODIDS.

Hydrogen Iodid.		*Potassium Iodid.*	
Iodin	99.22%	Iodin	76.42%
Hydrogen	0.78%	Potassium	23.58%
	100.00%		100.00%

Sodium Iodid.		*Silver Iodid.*	
Iodin	84.62%	Iodin	54.03%
Sodium	15.38%	Silver	45.97%
	100.00%		100.00%

Calculating, however, how much chlorin, bromin, and iodin combines with a unit weight of hydrogen, we get:

Hydrogen Chlorid.		*Hydrogen Bromid.*		*Hydrogen Iodid.*	
Chlorin	35.37	Bromin	79.75	Iodin	126.53
Hydrogen	1.00	Hydrogen	1.00	Hydrogen	1.00
	36.37		80.75		127.53

Calculating by simple proportion how much of the metals unite with these amounts of the haloids, *i.e.*, 35.37 parts of chlorin, 79.75 parts of bromin, and 126.53 parts of iodin, we obtain (as for instance in the case of potassium chlorid:

$$47.53 : 35.37 : : 52.47 : x. \quad x = 39.04$$

CHLORIDS.

Potassium Chlorid.		*Sodium Chlorid.*		*Silver Chlorid.*	
Chlorin......	35.37	Chlorin.......	35.37	Chlorin......	35.37
Potassium....	39.04	Sodium.......	22.99	Sodium......	107.66
	74.41		58.36		143.03

BROMIDS.

Potassium Bromid.		*Sodium Bromid.*		*Silver Bromid.*	
Bromin.....	79.75	Bromin......	79.75	Bromin......	79.75
Potassium...	39.04	Sodium......	22.99	Silver...	107.66
	118.79		102.74		187.41

IODIDS.

Potassium Iodid.		*Sodium Iodid*		*Silver Iodid.*	
Iodin.......	126.53	Iodin........	126.53	Iodin........	126.53
Potassium...	39.04	Sodium......	22.99	Silver	107.66
	165.57		149.52		234.19

From the above results it is at once apparent that the same amounts of metals which combine with 35.37 parts of chlorin also unite with 79.75 parts of bromin and with 126.53 parts of iodin. That is, 35.37 parts of chlorin replace 79.75 of bromin, or 126.53 of iodin, while 79.75 parts of bromin replace 126.53 of iodin, and so on.

Further, one and the same weight of a metal unites with 37.35 of Cl, 79.75 of Br, and 126.53 of I, and these are the amounts of these elements which unite with one part of H.

$$\text{1 part of H combines with} \begin{cases} 35.37 \text{ parts of Cl} \\ 79.75 \text{ `` `` Br} \\ 126.53 \text{ `` `` I} \end{cases}$$

$$\text{39.04 parts of K combine with} \begin{cases} 35.37 \text{ parts of Cl} \\ 79.75 \text{ `` `` Br} \\ 126.53 \text{ `` `` I} \end{cases}$$

Any number of examples can be given of this. Take, for instance, the oxids:

Cadmium Oxid.		*Copper Oxid.*	
Cadmium........	87.49	Copper.........	79.75
Oxygen..........	12.51	Oxygen..... ...	20.25
	100.00		100.00

Lead Oxid.		*Mercury Oxid.*	
Lead............	92.82	Mercury........	92.60
Oxygen..........	7.18	Oxygen.........	7.40
	100.00		100.00

If the weight of each metal united with one and the same weight of oxygen, say 15.96 parts by weight, be compared, the following numbers are obtained:

Cadmium Oxid.		*Copper Oxid.*	
Cadmium........	111.60	Copper.........	63.00
Oxygen..........	15.96	Oxygen..........	15.96
	127.56		78.96

Lead Oxid.		*Mercury Oxid.*	
Lead............	206.40	Mercury........	199.80
Oxygen..........	15.96	Oxygen.........	15.96
	222.36		215.76

From this it is evident that each of these metals unites with oxygen in fixed proportions, viz.:

111.60 parts by weight of Cd combine with 15.96 O
63.00 “ “ “ “ Cu “ “ “ “
206.40 “ “ “ “ Pb “ “ “ “
199.80 “ “ “ “ Hg “ “ “ “

We conclude, therefore, that the elements unite, or combine, with each other in definite and fixed proportions. This law was first stated by John Dalton, and is known as Dalton's Law of Definite and Constant Proportions.

The law is well stated as follows:[*]

I. *Definite Proportions.*—When two elements combine to form a particular compound substance, they do so in a definite, fixed proportion by weight, which is independent of the manner in which their combination is brought about.

II. *Constant Proportions.*—This proportion remains constant in compounds that contain also other elements.

COMBINATION IN MULTIPLE PROPORTIONS.

The fact that there exists more than one compound of two elements might lead one to suppose that there were exceptions to the law of Constant Proportions, but an examination of the matter will show that such is not the case.

Carbon and oxygen form two gaseous compounds, which on analysis are found to have the following percentage composition:

	Carbonous Oxid.	*Carbonic Oxid.*
Carbon.............	42.86%	27.27%
Oxygen.............	57.14%	72.73%
	100.00%	100.00%

At first sight it might appear that the law of Constant Proportions was at fault. On computing the relation of the oxygen to the carbon in each of these compounds, against the same amount of carbon, it appears that the amount of oxygen in the carbonic oxid is just twice the amount in the carbonous oxid:

	Carbonous Oxid.	*Carbonic Oxid.*
Carbon.............	11.97	11.97
Oxygen.............	15.96	31.92
	27.93	43.89
	CO	CO_2

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[*] Practical Proofs of Chemical Laws, Vaughn Cornish,

In the case of marsh gas and olefiant gas a similar relation is observed:

	Marsh Gas.	*Olefiant Gas.*
Carbon	74.95%	85.68%
Hydrogen	25.05%	14.32%
	100.00%	100.00%

Calculating the amount of hydrogen in each compound combined with 11.97 parts by weight of carbon (the atomic weight of carbon):

	Marsh Gas.	*Olefiant Gas.*
Carbon	11.97	11.97
Hydrogen	4.00	2.00
	15.97	13.97

From which it is evident that in marsh gas just twice the amount of hydrogen is united to 11.97 parts by weight of carbon as in olefiant gas. The simplest formulas would therefore be:

Marsh gas	CH_4
Olefiant gas	CH_2

The vapor density of olefiant gas proves, however, that its molecule is $CH_2 \times 2 = C_2H_4$.

The oxids of nitrogen afford an excellent example of multiple combination. The five oxids are:

1. Nitrous oxid	N_2O
2. Nitric oxid	N_2O_2
3. Nitrous anhydrid	N_2O_3
4. Nitrogen tetroxid	N_2O_4
5. Nitric anhydrid	N_2O_5

The percentage composition of this series is:

	1	2	3	4	5
N....	63.71%	46.75%	36.91%	30.51%	25.99%
O....	36.29%	53.25%	63.09%	69.49%	74.01%
	100.00%	100.00%	100.00%	100.00%	100.00%

Calculating the amounts of oxygen in combination with a fixed weight of nitrogen, say 28.02, which is twice its atomic weight, we get:

	1	2	3	4	5
N.....	28.02	28.02	28.02	28.02	28.02
O.....	15.96	31.92	47.88	63.84	79.79
	43.98	59.94	75.90	91.86	107.86

It is hence evident that the relative quantities of oxygen are in the ratio of the simpler numbers 1, 2, 3, 4, and 5. It has not been found possible to produce any other compounds of nitrogen and oxygen.

These facts are expressed in the *Law of Combination in Multiple Proportions*, which was first announced by Dalton. The two laws of Dalton state that the elements unite in the proportions of their atomic weights, or in multiples of these weights.

The reason for combination in multiple proportions is clear when it is borne in mind that only whole atoms, and in no case parts of atoms, can combine with each other. The relation between the weights of the elementary constituents of a compound must always be that of their atomic weights or multiples of them.

It is well expressed as follows: * "If there be more than one substance formed by the combination of two elements, then, taking the weight of one element as fixed in each substance, the weight of the other element in the second compound bears a simple proportion to the weight of that element in the first."

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* Practical Proofs of Chemical Laws, Vaughn Cornish.

CHEMICAL REACTIONS.

So far the particles of matter, molecules and atoms, have been studied merely in their relative number. Let us now consider some of the phenomena of chemical change. It has been shown that atoms exist in pairs, and that when certain of these atomic pairs are brought into contact with certain other atomic pairs a disintegration of the groups take place and new groups, or atomic pairs, are formed. For instance, when the hydrogen molecule is brought into contact with the molecule of chlorin, a disintegration of each molecule takes place, and new molecules are formed. This change can be represented in the following way:

$$(1) \qquad HH + ClCl = HCl + HCl.$$

On the left side of the equation are the atoms of the molecules before the reaction, while on the right side their arrangement is shown after the reaction. It is evident that the sums of the atoms of any element must be equal on both sides of the equation. As no matter is lost, the weight of matter on one side is equal to the weight on the other. In the same way the formation of water can be represented.

$$(2) \qquad HH + HH + OO = HHO + HHO.$$

These may be abbreviated by using numerals:

$$(3) \qquad H_2 + Cl_2 = 2HCl.$$

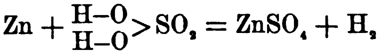
$$(4) \qquad 2H_2 + O_2 = 2H_2O.$$

The small numerals to the right of a symbol indicate the number of atoms in a molecule, the large numerals to the left of a symbol or formula indicate the number of molecules. Thus, $2H_2$ represents two molecules of hydrogen, or four atoms. The effect of the large numeral ceases at the sign of + and =. Thus, in $3Cu_2 + 16HNO_3 = 6Cu(NO_3)_2 + 2N_2O_2 + 8H_2O$ the 2 before N_2O_2 refers to the N_2O_2 and has no effect on the $8H_2O$. Parentheses are often used; *e.g.*, $6Cu(NO_3)_2$. The small 2 in this case refers to the contents of the parentheses and is affected by the large numeral 6. $6Cu(NO_3)_2 = Cu_6N_{12}O_{36}$. In cases of unusual complication brackets may be used with good results; *e.g.*, $8[K_2Al_2(SO_4)_4 24H_2O]$ = eight molecules of crystallized alum. The splitting of a formula in this manner, as will be seen, throws much light on the structure and architecture of the molecules and aids in understanding their behavior. So far as possible or convenient, it is best to express the substances as molecules. Thus, should 6N occur in an equation, it is better to write it $3N_2$. Cl_2 is better than 2Cl. If, however, an element, which is set free, acts in the nascent state (see below), it should be written as free atoms.

THE NASCENT STATE.

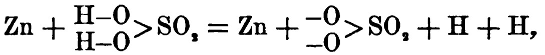
When two substances react on each other to form new substances, the change may be considered as taking place in two phases: First, analytic, in which the molecules break up into simpler atomic groups or into free atoms, as the case may be. Second, synthetic, in which the simpler atomic groups or free atoms unite among each other to form new molecules. If the reaction consists of two or more steps, then the second phase may be accompanied by a third phase in which some of the simpler atomic groups or free atoms attach other molecules and enter into reaction with them.

In the reaction

(5)


$$Zn + \begin{matrix}H-O\\H-O\end{matrix}>SO_2 = ZnSO_4 + H_2$$

there must be a period of time in which the atomic groups and atoms find themselves free, as

(6)


$$Zn + \begin{matrix}H-O\\H-O\end{matrix}>SO_2 = Zn + \begin{matrix}-O\\-O\end{matrix}>SO_2 + H + H,$$

although the period of time between this condition and that of the first reaction must necessarily be extremely minute when compared to our common standards of time. If while the hydrogen is in the atomic state, and before the atoms have had an opportunity to unite with each other to form a molecule, they come into contact with some substance for which they have a stronger affinity or desire for union than they have for each other, they will enter into reaction with it rather than unite with each other. An element or atomic group thus set free, and not united with itself to form a molecule, is called *nascent*, and the atom or group is said to be in the nascent state, *in statu nascendi*, which means, just born.

In the nascent state many elements are very active, which are entirely inactive after once they are united to form molecules.

Thus, if hydrogen gas is passed through nitric acid, there is no effect. But if the nitric acid is added to a mixture of zinc and dilute sulphuric acid, which is evolving hydrogen in accordance with the foregoing equation, and is thus exposed to nascent hydrogen, it is at once acted on and robbed of oxygen.

(7) $2HNO_3 + 5H = 2NH_3 + 3H_2O.$

Many applications are made of the activity of substances in the nascent state.

VALENCE.

In HCl each atom of chlorin is combined with one atom of hydrogen. In H_2O each atom of O is united to two atoms of H. In NH_3 one atom of N binds three atoms of hydrogen. In CH_4 marsh gas, a carbon atom binds four atoms of H. Hence, while the chlorin atom can bind one atom of hydrogen, the oxygen atom can bind two, the nitrogen atom three, and the carbon atom four. The power to bind, hold, or fix atoms is different with different elements. Taking the atom of hydrogen as a unit, we have:

Atomic binding power of Cl = 1.
" " " " O = 2.
" " " " N = 3.
" " " " C = 4.

The power of an atom to hold, bind, link, or to combine with certain numbers of other atoms is called its chemical worth, or *valence.* Valence is the attractive power, or chemism, of an atom expressed in terms of hydrogen. The chemism of the hydrogen atom is taken as unity in measuring valence.

Chlorin is mono-valent.
Oxygen is di-valent.
Nitrogen is tri-valent.
Carbon is tetra-valent.

There are atoms that are penta-valent, hexa-valent, and hepta-valent. A mono-valent atom is called a monad. We have also diads, triads, tetrads, pentads, hexads, and heptads. Atoms whose valence is odd are called perissads.* When the valence is even, they are called artiads.

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* That "p" follows "o" may help to recall that an atom whose valence is odd is a perissad.

Valence is expressed by placing ticks over the symbol, as Cl', O'', N''', or small Roman numerals when the valence exceeds three, as C^{iv}, N^{v}, S^{vi}. Also by strokes, as

$$\mathrm{Cl}- \qquad \mathrm{O}< \qquad -\overset{|}{\mathrm{N}}- \qquad -\overset{\|}{\mathrm{Sb}}= \qquad =\overset{\|}{\mathrm{S}}=$$

Cl— means that an atom of Cl is a monad and capable of binding a monad, as Cl—·—H. The stroke, —, represents chemical attraction, or chemism, equal to that of one atom of hydrogen. —O— does not mean that an atom of oxygen has two separate attractions radiating from it. It means that its attraction is double that of hydrogen, and, for the sake of clearness and convenience, its valence is expressed in hydrogen units.

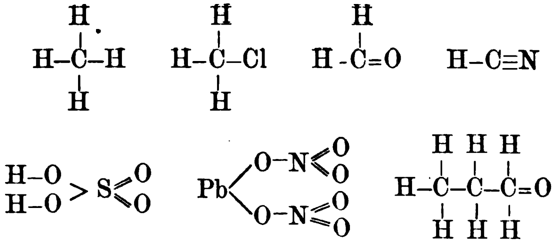
Thus, for the sake of convenience, the gram might be made the unit of weight in measuring the attractive power of a magnet, and the amount of the magnetism might be expressed in gram units. In such a case a magnet capable of supporting just four grams of iron might be expressed by $>4<$. It is evident that it is merely a matter of convenience where the signs of attraction are placed. It might be expressed

$$-\underset{|}{\overset{|}{4}}- \qquad \overset{|}{4}\equiv \qquad -\overset{\|}{4}- \qquad -\overset{|}{4}<, \text{ etc.}$$

It is also evident that such a magnet will support four one-gram weights, or two two-gram weights, or one one-gram and one three-gram weights:

$$1-\underset{\underset{1}{|}}{\overset{\overset{1}{|}}{4}}-1 \qquad \underset{\underset{1}{|}}{\overset{\overset{1}{|}}{4}}=2 \qquad 2=4=2 \qquad 1-4\equiv 3$$

The position of the valence-strokes is simply a matter of convenience in writing the formula, or in indicating the relation of the compound to others. Thus:



$$H-\overset{H}{\underset{H}{C}}-H \quad H-\overset{H}{\underset{H}{C}}-Cl \quad H-\overset{H}{C}=O \quad H-C\equiv N$$

$$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}=O$$

It is better to speak of the valence sign, not as a "bond," an "attraction," or an "affinity," but as a "valence." *

In these cases it must be clearly understood that the dash, stroke, or bond is used simply as a unit, and invariably represents a certain amount of attraction. When it is said that a stone weighs ten pounds, it is not meant that the stone is composed of ten stones each weighing a pound. It has been said by certain teachers that the use of the stroke to represent the attraction power of an atom of hydrogen is dangerous, inasmuch as (some) students get the idea that atoms have individual attractions sticking out of them. One might come to suppose that atoms resembled little flying balls covered with spines. But, as no trouble seems to result in the use of symbolic nomenclature in mathematics, there seems to be no reason to believe that any student will misunderstand the use of the stroke to represent the unit of valence, the chemism of the hydrogen atom. The stroke, dash, link, or bond represents, then, simply the attractive power, or chemism, of one atom of hydrogen, and when several of them are written after a symbol it is not meant

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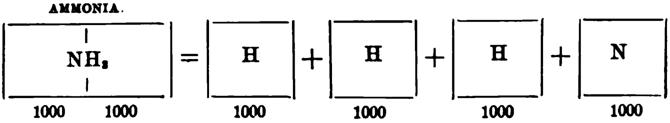
* In my quiz classes I call it a "val." Thus, oxygen has three vals, etc.

that the atom has several attractions, but that its attraction is several times that of a hydrogen atom. Thus, $—N=$ does not mean that N has three separate attractions, but that its chemism is three times that of hydrogen. When atoms unite, the attractions are supposed to satisfy each other; thus, the molecule of oxygen, $O=O$, might be compared to the union of two horseshoe magnets, the north and south poles of one being applied to the south and north poles of the other. The union of H— and Cl— may be written H—·—Cl. In this formula the dot marks the point of demarcation or fusion between the attractions of the two atoms. It is, however, common not to use a dot, but a single bond, as H—Cl, which represents the two attractions merged into each other. The dash or bond, when properly understood and used, is of immense convenience, and enables one to rapidly work out and understand the mechanism of chemical changes. Its symbolic character, however, must never be lost sight of.

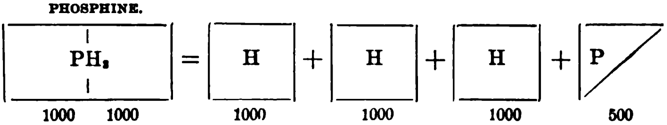
When an atom unites with another atom, it is supposed that the attractions are mutually satisfied, or very nearly so. That is, in the molecule H_2O, for instance, if there is any residual attraction, the chemism of the O not being exactly equal to that of 2H, this residue is so minute that its existence has not yet been established with certainty. It may therefore be considered that when two or more atoms unite to form a molecule the chemical work is done. The molecule is now a particle of composite matter, the constituents of which are held together by chemism. It is subject to physical attractions and motions, cohesion, adhesion, heat, etc. The chemical work is done in holding the atoms together.

ATOMICITY.

It has been shown that the molecules of oxygen, nitrogen, chlorin, and hydrogen consist of two atoms, and this is the case with most of the elementary molecules. There are, however, exceptions to this rule. If two liters of ammonia gas are decomposed, there are obtained, as has been explained,



from which the following deduction may be made: Since each liter of ammonia gas contained any assumed number of molecules, say 1000, and each molecule contained nitrogen, then in the two liters of ammonia gas there were 2000 atoms of nitrogen. From these two liters of ammonia gas there was obtained one liter of nitrogen, which must also contain 1000 molecules. Hence each of these molecules must consist of two atoms, because the 2000 atoms of nitrogen are contained in the 1000 molecules of nitrogen. There is a substance known as phosphine, which is composed of phosphorus and hydrogen. On electrolysis it gives



That is, a liter of it will yield three liters of hydrogen and half a liter of phosphorus gas. Again, assuming that a liter contains 1000 molecules, in the two liters of phosphine there are 2000 atoms of phosphorus, while in the right side there is half a liter, or 500 molecules. Hence each of the phosphorus molecules must consist of four atoms, since 500 molecules of phosphorus contain 2000 atoms. The same can be said of arsenic and antimony. Mercury and zinc, on the other hand, are considered to have but one atom in a molecule. The number of atoms in a molecule is called atomicity. Oxygen is diatomic; phosphorus, tetratomic; zinc, monatomic; ozone, triatomic.

In the case of a monatomic element its molecule and its atom are the same. In view of this the definitions of atom and molecule as usually given are not clear. A molecule is usually defined as the smallest particle into which matter can be divided without destroying its identity. This definition applies as well to the atom of a monatomic element. An atom is best considered as the smallest particle of matter that can exist and retain its identity, or as the smallest particle of matter that can enter into chemical combination.* A molecule is a group of two or more atoms united by chemism.

It is to be regretted that some writers use the word "atomicity" in the sense of valence, speaking, for instance, of an element as diatomic when divalent is intended.

ABSOLUTE EXISTENCE OF MASSES AND MOLECULES.

An interesting speculation may be indulged in as to the individuality of a molecule. A molecule of oxygen, if magnified sufficiently, would appear as two atoms. While it seems to move as a concrete particle, it is evident that it has no absolute existence. What constitutes its movement is really the resultant of the movements of the two constituent atoms. It is a convenient fiction. A mass of matter, as the earth, may be said to have no absolute existence, since it is a large mass composed of smaller masses, and each of these masses of molecules, and each of the molecules of atoms. All the properties of the earth, in this case, then, must be referred to the atoms. The cloud of mosquitoes, which has been mentioned, has no existence as a cloud, for it consists of a number of moving individuals, and its appearance as a cloud or mass is simply from our inability to distinguish the individuals that compose it; or, if we could see all the moving individuals, an inability of our minds to correlate the mass of motions into a concrete image. When a wheel is revolved at a certain speed, the spokes vanish. If the spokes are painted different colors, the tints blend and a uniformly colored disk is seen. *The conditions determine the observation recorded by the senses.* It is easy to understand how careful one must be in trusting the observations of untrained senses. A constellation appears as a milky blot on a blue basin, but a telescope resolves it into points of light, which are stars, and these in succession would disappear could we magnify them until we reached the atom. The motions of matter are infinitely complicated. The earth, for instance, revolving on its own axis, travels around the sun, and the sun moves through space on its own account, and this makes a sufficient intricacy of relations. But the earth is composed of solids, liquids, and gases, which consist of particles flying, whirling, and oscillating, and these particles consist of atoms which also have motions of their own. The mind soon ceases to follow such a vast snarl of motions. The following illustration will show how form and the apparent existence of objects are owing to the inability of the senses to disintegrate: Tie a ball to the end of a string and whirl it around. When the ball has attained a sufficient velocity, it vanishes, and a circle is seen. Keeping up the revolution of the ball, tie the string to the end of a cane and move this cane rapidly so that the end to which the string is tied describes a circle. The apparent circle described by the ball becomes now a broad band. There are now two rings, or revolutions, to study, but the ball is the source of each. By increasing the number of various revolutions complicated forms would be seen. Should the velocity of the ball vary, still more complicated and apparently less related forms would appear. These might be studied and their characteristics collated. But it is evident that they have no existence, and are really the result of blurs in the eye; that is, one impression laps on another. All that there really is is a ball moving rapidly over a complicated path. Following out this line of thought, it is evident that, inasmuch as our senses are imperfect, and efficient to but a very limited degree, all our observations are relative and crude. Form, color, etc., the properties of material objects are not absolute properties, but express the degree of limitation of the particular sense of the observer. There are doubtless properties of matter that we are not cognizant of, as their detection calls for senses which we do not possess.

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* It is supposed that argon does not combine with other elements. Hence the second definition will not apply to its atom.

Since a mass has no real existence, it is evident that the so-called mass-attractions can have no real existence. Gravitation, cohesion, etc., are thrown out with the mass. The thought appears strange, but reflection will make it easier. The idea of an attraction, *i.e.*, two bodies *pulling* each other together, is in itself absurd. It was, in fact, so considered by Newton. The attraction between two bodies seems to really be the absence of resistance between them to external pressure. To understand the real mechanism of matter we shall have to refer all its forms to their ultimate condition. We have no idea what that is.

It is interesting to note in connection with existence of mass as indicating the limitation of the senses that the Buddhistic philosophy considered the nature of composite objects in a somewhat analogous way many years ago.

MATTER AND SENSATION.

While the phenomena about us are satisfactorily explained by the atomic hypothesis of matter, there is a bottomless and unbridgeable gulf between matter and sensation. That is, while we can understand how light and heat may be simply modes of molecular motion,* it is not easy to understand how the tapping of a material particle against a nerve-point gets turned into a sensation. In fact, things do not exist in reality as we feel them. Particles in vibration strike our nerve-points in one way and we see light and color, in another way and we feel heat. But light and heat do not exist as such. They are vibrations of material particles. Our nerves and brains transmute them into forms of sensation. Brains and nerves constructed on a different plan might translate them into very different sensations. These forces, light, heat, and so on, are not strongly individualized. What a moment since was heat is now light, is next sound. A thrill of electrical energy may appeal to our senses as a brilliant glare of light, the whispered word of a friend, or a myriad of atoms held in bondage to show forth by their relations the familiar scene as a photograph. The beautiful landscape that may charm you is a clockwork of atoms in you, not out of you. It is the brain that enables one to make beauty out of all these swarms of particles. Strike the eye and a flash of light is seen, but no light has existed. The optic nerve has deceived the brain. Unless a picture is observed from the focal point at which the artist painted it, all is distortion, crude, and inartistic.

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* Compare Ganot's, Barker's, and Deschanel's Physics.

In view of the difficulty of getting out of ourselves, some philosophers in the past and some in the present have preferred to consider all phenomena as occurring within us. In his *Einleitung zum Studium der Chemie* Prof. Schiff, of Turin, expresses the idea as follows: " To find out the causes of the impressions which we are conscious that our senses receive, and which give rise to sensations, we examine into what is taking place in our organisms. In some cases we cannot find any reason for the impression, or sensation, outside of our own organism. These we call subjective impressions, or sensations. In many other cases we believe that we can find a reason for the sensation in something happening in the space not occupied by our organism, that is, outside of it. These we call objective impressions. We call them objective because we think that we are justified in supposing that in the space not occupied by our organisms there are objects which can so act upon our organs at that moment as to give rise to the impression, or sensation. All of these things which fill space taken together, without taking into account the difference in the impressions caused by them, we call substance, or matter, in order to designate the variety of impressions which are caused, or brought about, by the masses of matter about us, and the fixed properties that they possess.

" From our earliest childhood it is represented to us that there is something else besides ourselves in the space about us. That is, the idea of that which is generally termed the existence of matter is most intimately combined with all our acts, our thoughts, and our whole mental development. In all the relations of our life we feel so dependent on this idea that at all times we fall back on this general and fundamental assumption, and we are not permitted to take a single step without doing so. Hence we are accustomed to speak of matters and of bodies as if we had the fullest certainty of their actual existence, as if this existence were the direct and indirect cause of our sensations and impressions, and in no way could be doubted.

"Actually, however, we are not able to decide whether material things exist outside of our sensations, or whether everything behaves constantly and under all conditions as if a something like matter existed in a state always identical with itself. To those who claim too great importance for the existence of matter we must remember that the acceptance of the existence of matter does not in any way remove all the difficulties of understanding phenomena, for in this case it is necessary to form a clear idea of what way matter outside of our sensorium can act upon it so that a sensation is produced. We must openly confess that we have not the slightest idea of how to bridge the gap between matter and sensation. Assuming, however, the actual existence of our sensations as an approach to balancing the contradictions presented to us, we shall consider matter and the bodies about us as actually existing, so far as we mention them as causes of our sensations. We shall proceed as if the existence of matter were an undoubted fact. We assume, or suppose, that material things are able to act on our peripheral, or external, organs in such a way that the external excitation is carried by our nervous system to the internal organs, producing sensations, or impressions. A number of such sensations, caused by one or more bodies when united, classed together, or compared with each other, gives rise to what we call an observation, particularly of a body, or of several bodies. The observations to which material things may give rise will be of a very different kind, depending on the nature of the things, the physiological state of our organism, and the mental development of the individual. But, so far as we are concerned, two classes alone of observations are to be distinguished:

"1. Observations relating to the external properties of bodies—form, color, transparency, expansion, etc.

"2. Observations not depending on these properties, but on changes of which the bodies are capable.

"Both groups of observations can be united by logical principles to scientific systems. The collated observations of the external properties of bodies are called descriptive natural history, or natural science; while the observations relating to the changes of the bodies form the subject of experimental natural science, or physical science."

The idea of the non-existence of matter was discussed, from a metaphysical standpoint, by Bishop Berkeley.* Among the later thinkers Max Müller † has come to the same opinion from philological considerations. It is interesting to note how much more easily this subject is handled when it becomes a matter of scientific investigation than when it is treated as a branch of idealistic speculation.

SMOKE-RINGS AND VORTEX-ATOMS.

In regard to atoms there have been several speculations. The most remarkable hypothesis, and one which is of a "perfectly unique, self-contained character," is that of vortex-atoms. As is explained in works on physics, all space is supposed to be filled with an exquisitely ethereal fluid. In this ether there are formed by some agency smoke-rings, or vortices Every one has seen the revolving rings of smoke blown by a smoker, or rings of steam sent up by a locomotive. Such rings, revolving on themselves, and composed of the infinitely subtile ether, are supposed to be the form of the atoms.

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* Principles of Human Knowledge, edited by Krauth.

† The Open Court, Vol. 1, page 283.

"The postulates of this theory are few and simple, but the working out of anything beyond their immediate consequences is a task to tax to the utmost the powers of the greatest mathematicians for generations to come. A vortex-filament, in a perfect fluid, is a true 'atom,' but it is not hard, like those of Lucretius; it cannot be cut, but that is because it necessarily *wriggles* away from the knife."* Matter, then, when closely followed up, resolves itself into motion. That which moves yet eludes us.

Let us make an experiment. Fill a glass with water. The fluid rests clear and motionless to the view. Let us imagine that it is our subtile, ethereal, continuous fluid. A drop of the water is raised and allowed to fall. It strikes, and, looking down, we see but a passing ripple vanishing from the surface. But look through the water and what do we see? An active smoke-ring of water, a vortex-atom. Has the dead drop of water become a thing of life? It strikes the side of the glass, it bounds back, but, as we watch it, its motion grows feebler, it loses its shape, breaks, and with a few feeble convulsions soon disappears, is dead, and the water is again clear and still. Water was in the glass, the vortex-ring was water, both were the same water, and yet we saw this individual spring into existence and live its short life—short in time, but involving in those few moments more science and more mathematics than all the great minds of to-day are capable of. It was energy made visible.† This illustration gives one an idea of how it is possible for vortex-atoms to form in the ether. On the other hand, should atomic motion cease, worlds, suns, the entire Cosmos, would be resolved back to the primal ether, as a palace of ice melts to water and leaves no trace of structure or design apparent to human eye.

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* Tait, Properties of Matter, page 19. Read also in this admirable work the hypotheses of Lucretius, Boscovich, and Thomson.

† Phi Beta Kappa Address on Scientific Speculations, 1887. P. T. A.

DEFINITION OF CHEMISTRY.

Chemistry is that branch of physical science which treats of the atomic composition of bodies, and of those changes in matter which result from an alteration in the kind, the number, or the relative positions of the atoms which compose the molecules. (Frankland-Barker.)

Matter appears to have been reduced to the motions of an ether. This ether is probably but the starting-out point of a series of gradations far too minute and abstruse for us with our present limited mental capacities to investigate. That is, we understand things by continually adding to our stock of knowledge. We establish some kind of a bridge or link of relation between our present knowledge and the new fact. We understand facts by means of facts. An isolated fact could hardly be conceived to exist in our minds. If it did, we should have no means of recalling it or getting at it. The study of the ether is as yet next to impossible, since we have no certain paths by which to reach this domain, nor have we any tools to work with should we get there. On the other hand, going up the scale we also get bewildered. A constellation, such as ours, *i.e.*, a few planets revolving about a sun, when viewed from a distance, would have a definite form. Indeed, it might be considered as a molecule, the planets and sun being the atoms.* Several such constellations would then form a mass. The speculation, however, is difficult, because the mind works very unsatisfactorily when dealing with either very large or very

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* Compare Pflüger, Wesen und Aufgaben der Physiologie.

(Adapted from Barker's Chemistry.)

THE RELATION OF THE SCIENCES.

SCIENCE.

Classified knowledge of external nature.

NATURAL SCIENCE	PHYSICAL SCIENCE
considers external form and internal structure of bodies. (Geology, mineralogy, botany, zoology, etc.)	concerns itself with the matter of which bodies are made. It is divided into—

PHYSICS.	CHEMISTRY.
That department of physical science which studies the results that arise from the molar and molecular conditions of matter. Weight is a result of mass-attraction; impact, of mass-motion; tenacity, hardness, and elasticity, of cohesion; solution, capillarity, and diffusion, of adhesion; heat, light, electricity, and magnetism are modes of molecular motion. A *physical change* takes place outside of the molecule, does not affect the molecule itself, and hence does not alter the identity of the matter. Properties possessed in virtue of molar or molecular condition are physical. (Density, tenacity, color, etc.)	That department of physical science which studies the results that flow from the atomic condition of matter. It accounts for the difference observed in the various kinds of homogeneous matter, and investigates the changes that this matter may undergo. A *chemical change* takes place within the molecule, alters the condition of the molecule, and hence causes a change in the matter itself. Identity of the matter is altered. Properties possessed in virtue of atomic composition of the molecule are chemical. (Combustibility, explosibility, capability of union with, or of action upon, other bodies.)

(Adapted from Barker's Chemistry.)

STUDY OF MATTER.

Physical Science considers	**The Divisions** of which it is capable.	**Mass.**—Any portion of matter appreciable by the senses. (Two or more molecules.)
		Molecule.—Smallest particle of matter into which a body can be divided without losing its identity. (Two or more atoms.)
		Atom.—Smallest particle of matter that can exist.
	The Attractions by which the divided particles can be held together.	**Gravitation.**—Exerted between masses.
		Cohesion.—Binds *like* molecules together, forming homogeneous matter.
		Adhesion.—Binds *unlike* molecules together, forming heterogeneous matter.
		Chemism.—Binds atoms together.
	The Motions which these particles may have.	**Mass.**—Visible or mechanical motions.
		Molecular.—Motion of molecule within the mass. (Heat, light, electricity, etc.)
		Atomic.—Probable, but not yet fully established.

small quantities, or with generalizations of magnitude or minuteness. The term "physical science," used in the definition of chemistry, at once gets into trouble when attacked. Physical science is the study of matter, and is a branch of science. We have seen that matter fares badly when investigated, and at once eludes us by disappearing into subtile ether. So much for "physical." Science has been called a "classified knowledge of external nature." But one asks, How perfect is the classification? External to what? What is nature? A mass of matter is defined as "any portion of matter appreciable by the senses." But a particle of matter may be too small to be detected by the senses and still not be a molecule. Attention is directed to these considerations to emphasize how relative all knowledge is, and how inexact much of it is, and also how loosely many of the best of us sometimes express ourselves.

CLASSIFICATION OF REACTIONS.

(Adapted from Barker's Chemistry.)

1. *Analytical Reactions.*—Separation of a complex molecule into simpler ones.
2. *Synthetical Reactions.*—Union of two or more simple molecules to form a complex one. Converse of analytical.
3. *Metathetical Reactions.*—Transposition or exchange of atoms between molecules.
4. *Migratory Reactions.*—Rearrangement of the atoms in a molecule to form a new molecule. (Atomic migration.)

EXAMPLES.

$$(8)\quad \underset{\textbf{Ammonium nitrate.}}{NH_4(NO_3) + \text{heat}} \;=\; \underset{\textbf{Nitrous oxid.}}{N_2O} \;+\; \underset{\textbf{Water.}}{2H_2O.}$$

$$(9)\quad \underset{\textbf{Calcium oxid.}}{CaO} \;+\; \underset{\textbf{Carbon dioxid.}}{CO_2} \;=\; \underset{\textbf{Calcium carbonate.}}{CaCO_3.}$$

(10) $AgNO_3 + NaCl = AgCl + Na(NO_3)$.

Silver nitrate. Sodium chlorid. Silver chlorid. Sodium nitrate.

(11) $CON(NH_4) = CO(NH_2)_2$.

Ammonium cyanate. Urea.

MODES OF CHEMICAL ACTION.

(Adapted from Barker.)

Chemical changes in matter may take place in five different ways, namely:

1. By the direct union of simple molecules to form a more complex one.

All synthetical reactions belong to the first class of chemical changes; as:

(12) $Zn + Cl_2 = ZnCl_2$.

Zinc. Chlorin. Zinc chlorid.

2. By the separation of a complex molecule into simpler ones.

All analytical reactions belong to the second class; as:

(13) $H_2SO_4 = H_2O + SO_3$.

Hydrogen sulfate. Water. Sulfuric oxid.

3. By the substitution in a molecule of one atom, o. group of atoms, for another or for several others.

(14) $C_2H_6 + Cl_2 = C_2H_5Cl + HCl$.

Ethane. Chlorin. Ethyl chlorid. Hydrogen chlorid.

4. By the mutual exchange of atoms between molecules.

(15) $CaCl_2 + K_2(C_2O_4) = Ca(C_2O_4) + 2KCl$.

Calcium chlorid. Potassium oxalate. Calcium oxalate. Potassium chlorid.

All metathetical reactions belong to the third and fourth classes.

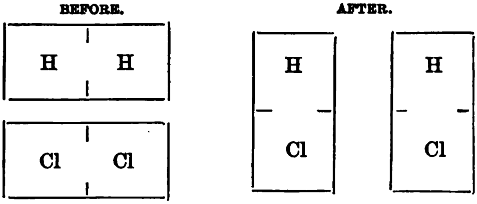
5. By a rearrangement of the atoms within a single molecule. All migratory reactions belong to the fifth class.

(16) $$(NH_4)(NCS) = (CS)(NH_2)_2.$$

Ammonium sulfocyanate. Thio-urea.

AFFINITY.

Let us study the synthesis of muriatic acid. We may represent the molecules before and after the reaction as follows:



When should an atom of chlorin leave its partner and take up with the atom of hydrogen—indeed, take it away from its partner? This chemical change is explained by supposing that the tendency to union is greater between a chlorin atom and a hydrogen atom than between two chlorin atoms, or between two hydrogen atoms. Therefore the hydrogen atoms and the chlorin atoms are torn apart, and for an instant exist as free atoms, but immediately reunite in a different order.

To get a clearer idea of this matter the thermo- and electro-chemical properties of the elements must be studied. Under the head of Valence the *quantity* of the chemism of the atoms was considered. The *quality* of the chemism, however, is a subject not so easily explained, nor, indeed, so well understood, although progress has of late been made in this direction by the aid of physical chemistry. Some elements unite with certain other elements much more easily than with others. There are some elements, as fluorin and oxygen, for instance, that cannot be made to unite with each other at all. Certain elements will drive certain other elements out of compounds and take their places. When hydrogen bromid is treated with chlorin, there is a greater affinity, or tendency toward union, between the hydrogen and the chlorin than between the hydrogen and the bromin; hence the following change occurs:

$$(17) \qquad HBr + Cl = HCl + Br.$$

It is to be observed that each of these elements is a monad; that is, the quantity of the attractive power is in each case the same. But it is evident that the desire for union between them, *i.e.*, their *affinity* for each other, or tendency toward union, is not the same. To explain this phenomenon it is necessary to briefly explain some of the principles of electro-chemistry.

When substances are submitted to the action of the electric current, they are decomposed, as has already been observed in several typical examples. Certain of the elements are liberated at the positive pole and others at the negative pole. As, for instance, in the case of hydrochloric acid, the hydrogen is liberated at the negative pole and the chlorin at the positive pole. Elements that are liberated at the positive pole are called negative, and those set free at the negative pole are called positive.

The electro-chemical nature of the elements is much more marked in some than in others, some, as lithium and potassium, being very strongly positive, and others, such as oxygen and sulfur, being strongly negative. Then there are others, the character of which is not so marked. Antimony and arsenic are examples of such elements. They are neither strongly negative nor positive. The more widely the electro-chemical natures of the elements differ the stronger will be their tendency toward union, or, as it is properly called, their *affinity* for each other.*

Other things being equal, then, a powerfully negative element will eject a less powerfully negative element that is in combination with a strongly positive element and take its place, replacing or substituting it. In the reaction

$$\text{KBr} + \text{Cl} = \text{KCl} + \text{Br} \tag{18}$$

the chlorin ejects, replaces, or substitutes the bromin in the molecule of potassium bromid, because it is more powerfully negative than the bromin, and hence has a greater affinity for the potassium than the bromin has.

It should be clearly understood that although two elements may each have a powerful chemism, it does not follow that they will attract each other. Thus, fluorin and oxygen are each very active elements, but no union has been induced between them. Nitrogen and chlorin are very active elements when in combination, but the compound, nitrogen iodid, is so loosely held together that a mere touch causes an explosion. The matter may appear clearer if we examine magnetic attraction. If the north pole of a magnet be applied to the south pole of an equally strong magnet, there will be a powerful attraction manifested and the two ends will be brought together by the attraction. But if the north pole of a magnet be applied to the north pole of another magnet, then no attraction will be observed between the ends, but, on the contrary, a repulsion.

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* Few words have been more abused than "affinity." In the sense to denote the tendency, or desire, to combine the word is properly used. But to denote the quantity of attraction, chemical worth, or valence, as when an element is spoken of as having two or more "affinities," the word is misleading.

The electro-chemical equilibrium of a molecule determines its stability. If the elements constituting the molecule are not of a pronounced electro-chemical character, or if they are of the same electro-chemical nature the compound will be a weak one. The more widely the elements differ in their electro-chemical nature, the more stable will be the compound. The chemism of the polyvalent elements seems to be both positive and negative, one or the other predominating. This is also in accordance with the hypothesis that chemism is a polar force.* There are many interesting instances of alterations in the stability of molecules caused by changes in the electro-chemical relations. Thus, potassium methid, CH_3K, is a very unstable compound; is, in fact, explosive by percussion. The reason of this unstability is that the chemism of carbon is not strongly negative, and hence has difficulty in binding three atoms of hydrogen, which are weakly positive, and one atom of potassium, which is a strongly positive element. The powerful positive character of the chemism of the potassium is not neutralized by that portion of the chemism of the carbon atom that binds it. If, however, the positive chemism of the carbon atom be neutralized by a strongly negative atom, then the remaining chemism will be more decidedly negative. Thus, if in CH_3K the three atoms of hydrogen be substituted by the strongly negative atom of nitrogen, the positive chemism of the carbon atom will be consumed in binding the nitrogen atom. The negative portion of the chemism of the carbon atom will be then concentrated in the chemism that binds the atom of potassium, and will hence make a powerful union. We have then

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* My experience in teaching chemistry leads me to feel that it is best to explain the thermo- and electro-chemistry of reactions later on. With the beginner, however, I find it inadvisable to introduce the study of the thermic and electric relations of reacting substances. When a stock of knowledge of chemical substances and their action on each other has been accumulated the study of the higher chemistry is much easier and also much more effective. To the question continually asked by students, "Why do substances behave as they do?" one can answer only, "Wait. Observe facts first. Seek causes later."

$C^{iv}H_3'K'$;	$C^{iv}N'''K'$.
Potassium methid. **Unstable, explosive.**	**Potassium cyanid.** **Stable.**

Many other examples could be easily adduced. The following, which is more intricate, must suffice:

C_6H_6, benzene.
C_6H_5Cl, monochlorbenzene.

The chlorin atom is powerfully bound by the positive chemism of the C_6H_5 rest. It cannot be affected by silver salts, potash, or ammonia. By inserting other negative atoms, or groups, the positive chemism of the C_6 complex will be consumed, distributed or more or less directed from the chlorin, and hence the bond of union between the C_6 complex and the chlorin will be weakened. Inserting the strongly negative rest nitroxyl, NO_2, we have

$C_6H_4(NO_2)Cl$, mononitrochlorbenzene.

The reaction

(19) $C_6H_4(NO_2)Cl + NH_3 = C_6H_4(NO_2)NH_2 + HCl$

takes place when aided by heat and pressure:

$C_6H_3(NO_2)_2Cl$, dinitrochlorbenzene.

The reaction

(20) $C_6H_3(NO_2)_2Cl + NH_3 = C_6H_4(NO_2)_2NH_2 + HCl$

takes place in the cold:

$C_6H_2(NO_2)_3Cl$, trinitrochlorbenzene.

The reaction

(21) $C_2H_2(NO_2)_3Cl + NH_3 = C_6H_2(NO_2)_3NH_2 + HCl$

takes place in the cold with explosive energy. The increasing instability of the molecule by overloading it with negative atoms, and its consequent increasing desire for positive atoms, in order to restore its equilibrium, is clearly illustrated by these examples.

SUBSTITUTION OR REPLACEMENT.

The principle of replacement, or, as it is more commonly called, of substitution, is of great importance in chemical changes. For instance, if tin is dissolved in hydrochloric acid, we have

(22) $$Sn + 2HCl = \underset{\text{Stannous chlorid.}}{SnCl_2} + H_2.$$

If a piece of zinc be placed in the solution of stannous chlorid, the tin will be precipitated and the zinc will take its place:

$$\underset{\text{Stannous chlorid.}}{SnCl_2} + Zn = \underset{\text{Zinc chlorid.}}{ZnCl_2} + Sn. \tag{23}$$

If a strip of magnesium is placed in the solution of zinc chlorid, the zinc will be precipitated:

$$\underset{\text{Zinc chlorid.}}{ZnCl_2} + Mg = \underset{\text{Magnesium chlorid.}}{MgCl_2} + Zn. \tag{24}$$

It is said that the magnesium substitutes, or replaces, the zinc.

In organic chemistry substitution appears more prominently than in inorganic. Thus, in CH_4, methane, a great number of substitutions can be made; *e.g.:*

$$\begin{array}{llll} C^{iv}H_4, & CH_3Cl, & CH_2Br'Cl', & CH(NO_2)_3', \\ CH_2O'', & CH_3(OH)', & CH_3(CN)', & CH_3(CH_3)'. \end{array}$$

The stability of the molecule as determined by the electro-chemical relations of its constituent atoms, its composition, structure, and environment, increases or decreases, as the case may be, the possibilities of substitution.

It might appear that when an atom substitutes another, there must be a greater affinity for it than the one it replaces, and, indeed, this is true for one compound in every reaction, but other substitutions may take place as the result of this first substitution, and these secondary substitutions often produce molecules of decreased stability, as there is less affinity for the atom substituting than for the atom substituted. This may appear somewhat paradoxical, but a few minutes' thought will make it clear.

For instance, in the reaction

$$NH_3 + 3Cl_2 = NCl_3 + 3HCl \tag{25}$$

the affinity between hydrogen and nitrogen is far greater than between nitrogen and chlorin. NH_3, ammonia, is a permanent substance, but NCl_3, nitrogen chlorid, explodes at a touch. In every reaction there is a motive, which, when found, explains the mechanism of it. In the reaction thus given the initial change is found in the affinity of the chlorin for the hydrogen, which is greater than that between nitrogen and hydrogen, or that between chlorin and chlorin. The hydrogen takes enough chlorin to pass into hydrochloric acid. The nitrogen and the rest of the chlorin are left together and have no other course than to form an unwilling and uncongenial union, and one that is ruptured by the slightest jar with explosive energy. The substitution of the H of NH_3 by Cl may, then, be considered not as a primary action, but a secondary necessity.

RESTS.

It has been found of great convenience in formula-writing to make use of what are called rests, residues, or radicals. A rest is an unsatisfied molecule. It may have an active existence, as, for instance, carbonous oxid, $(CO)''$, or it may be a group of atoms not existing in the free state, but common to a number of compounds, as $(NO_3)'$. All such unsatisfied groups are called rests, and may be considered as rests, or residues, left by the elision of atoms from satisfied molecules, which may be either actually existent or hypothetical. Thus, $(OH)'$, hydroxyl, is a rest of H_2O, water; $(NH_4)'$ is a rest of NH_5, the hypothetical ammonium; $(NH_2)'$, amidogen, is a rest of NH_3, ammonia; $(NO_3)'$ is a rest of HNO_3, nitric acid; $(Pb(OH))'$ is a rest of $Pb(OH)_2$, lead hydroxid. The use of rests enables us to classify compounds with great ease, and to make clear many important relations existing between them.

For instance, it is not usually necessary to dissect the formulas of acids further than to show the number of hydroxyl rests in them; *e.g.:*

$(HO)NO_2$;	$(HO)_2SO_2$;	$(HO)_3P$.
Nitric acid.	**Sulfuric acid.**	**Phosphorous acid.**

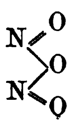
BINARY AND TERNARY MOLECULES.

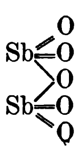
Molecules are divided into two classes, binaries and ternaries. Binary molecules contain only two different kinds of atoms. Examples: hydrochloric acid, HCl; water, H_2O; manganese dioxid, MnO_2; stannic chlorid, $SnCl_4$.

Ternary molecules contain three or more different kinds of atoms. Examples: hypochlorous acid, $HOCl$; carbon oxysulfid, COS; sulfuric acid, H_2SO_4.

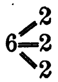
When a binary molecule is composed of two artiads, the formula can be obtained at once by dividing the valence of the greater atom by that of the lesser. For instance, the simplest compound of S^{vi} and O'' is SO_3, the relation being $6 \div 2 = 3$. When one atom is an artiad and the other a perissad, then the least common multiple of the two valences divided by the valence of each gives the number of atoms to be taken. Thus, the simplest compound of N^{v} and O'' is N_2O_5. The least common multiple of 5 and 2 is 10. $10 \div 5 = 2$. $10 \div 2 = 5$.

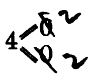
The student will do well to practice writing the structural formulas of binary molecules without paying attention to whether they represent known or possible compounds. Thus, write the combinations each with the other of Cl', O'', N''', C^{iv}, Sb^{v}, S^{vi}, keeping the symbols in two parallel vertical columns; as:

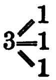


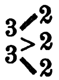


If it is not considered advisable to write formulas of compounds that are not known, use the numerals instead of symbols:









NOMENCLATURE OF BINARY MOLECULES.

In writing the symbol of a binary molecule the more positive element is placed first, the more negative element last. The molecule is named by placing first the name of the positive element and second the name of the negative element, changing its last syllable or syllables, as the case may be, to "id." Thus:

$NaCl$,	sodium chlorid.
NH_4Br,	ammonium bromid.
BaS,	barium sulfid.

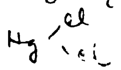
It may happen, however, that there is more than one compound containing the same elements. This is caused by the positive elements acting with different valences. For instance, tin as a diad forms $Sn''Cl_2$, and as a tetrad $Sn^{iv}Cl_4$. In such cases the termination of the positive atom is changed to "ous" when the lesser valence is indicated, and to "ic" when the greater valence is to be represented:

$Sn''Cl_2$,	stannous chlorid.
$Sn^{iv}Cl_4$,	stannic chlorid.
$Sb_2'''S_3$,	antimonous sulfid.
$Sb_2^{v}S_5$,	antimonic sulfid.

The same nomenclature is used when two compounds, formed from the same elements, differ, not by a change of valence, but in number of the basic atoms. In this case the termination "ous" is used to indicate the compound containing the greater amount of the basic (positive) element, or, what is the same thing, the lesser amount of the acid (negative) element:

Hg_2Cl_2, mercurous chlorid.
$HgCl_2$, mercuric chlorid.

Cl-Hg-Hg-Cl



When there are more than two relations involved, the prefix " hypo," meaning under, is added, which indicates that the available valence or number of the basic atoms is less than that indicated by " ous." When higher than that represented by " ic," the prefix " per " is added. In all of the cases, however, the termination of the negative element is changed to " id."

Sometimes the prefix " hypo " is added to the name of the element the termination of which has already been changed to " ic." This usually is in case of the discovery of a compound that falls between two others to which the " ous " and " ic " terminations have already been assigned; as:

V_2O_2, hypovanadous oxid.
V_2O_3, vanadous oxid.
V_2O_4, hypovanadic oxid.
V_2O_5, vanadic oxid.

There is another compound in the above series, V_2O, for which, under this system, there is no name. In such cases, and in many others, where doubt may arise as to the compound meant, it is customary to name the compound from its numerical composition. Thus, the above series would be:

V_2O, vanadium monoxid.
V_2O_2, vanadium dioxid.
V_2O_3, vanadium trioxid.
V_2O_4, vanadium tetroxid.
V_2O_5, vanadium pentoxid.

And again:

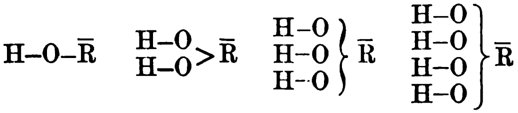
Mn_3O_4,	trimanganic tetroxid.
CO_2,	carbon dioxid.
CO,	carbon monoxid.
U_3O_8,	triuranic octoxid.

ACIDS, BASES, AND SALTS.

Inorganic acids may be divided into hydrogen acids and oxygen acids. As the former are simply binary compounds, they do not need further consideration. The substances formed from them by the replacement of the hydrogen atom by a metal are often called *haloid salts; e.g.:*

$H-Cl$	$Na-Cl$
Hydrochloric acid. (Hydrogen chlorid.)	Sodium chlorid. (Salt.)

An oxygen acid is a compound that consists of hydrogen bound by oxygen to one or more negative atoms, or rests. Representing the negative atom, atoms, or atomic group by $\bar{R}$, the general type of acids may be represented as follows:

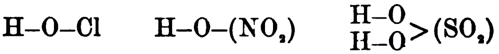


$$H-O-\bar{R} \qquad \begin{matrix}H-O\\H-O\end{matrix}>\bar{R} \qquad \left.\begin{matrix}H-O\\H-O\\H-O\end{matrix}\right\}\bar{R} \qquad \left.\begin{matrix}H-O\\H-O\\H-O\\H-O\end{matrix}\right\}\bar{R}$$

Instead of oxygen atoms other negative atoms or rests may act as links, as, for instance:

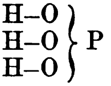
$$H-S-\bar{R} \qquad \begin{matrix}H-S\\H-S\end{matrix}>\bar{R}$$

As examples of well-known acids we have:



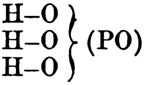
$$H-O-Cl \qquad H-O-(NO_2) \qquad \begin{matrix}H-O\\H-O\end{matrix}>(SO_2)$$

Hypochlorous acid. Nitric acid. Sulfuric acid.



$$\left.\begin{array}{l}H{-}O\\H{-}O\\H{-}O\end{array}\right\}P$$

Phosphorous acid.



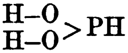
$$\left.\begin{array}{l}H{-}O\\H{-}O\\H{-}O\end{array}\right\}(PO)$$

Phosphoric acid.

$H{-}O{-}(SbO_2)$

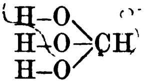
Metantimonic acid.

Negative rests not containing oxygen may form acids:



$$\begin{array}{l}H{-}O\\H{-}O\end{array}{>}PH$$

Hypophosphorous acid.



$$\left.\begin{array}{l}H{-}O\\H{-}O\\H{-}O\end{array}\right\rangle CH$$

CH

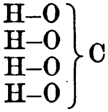
Orthoformic acid.

Acids are divided into two classes, ortho and meta. An *ortho acid* is one in which all the oxygen has a linking function; *e.g.:*

[illegible]

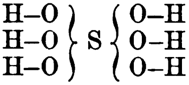
$H{-}O{-}Cl$

Hypochlorous acid.



$$\left.\begin{array}{l}H{-}O\\H{-}O\\H{-}O\\H{-}O\end{array}\right\}C$$

Orthocarbonic acid.

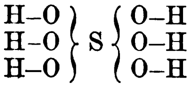


$$\left.\begin{array}{l}H{-}O\\H{-}O\\H{-}O\end{array}\right\}S\left\{\begin{array}{l}O{-}H\\O{-}H\\O{-}H\end{array}\right.$$

Orthosulfuric acid.

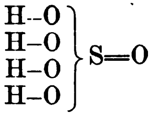
In ortho acids there must be the same number of atoms of oxygen and hydrogen, or, what is the same thing, the number of hydroxyls is equal to the valence of the negative atom, or group.

When one or more molecules of water are eliminated from an ortho acid, a *meta acid* results. Thus, orthosulfuric acid yields meta acids as follows:



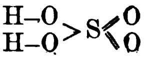
$$\left.\begin{array}{l}H{-}O\\H{-}O\\H{-}O\end{array}\right\}S\left\{\begin{array}{l}O{-}H\\O{-}H\\O{-}H\end{array}\right.$$

Orthosulfuric acid.



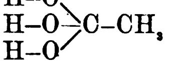
$$\left.\begin{array}{l}H{-}O\\H{-}O\\H{-}O\\H{-}O\end{array}\right\}S{=}O$$

Monometasulfuric acid.



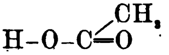
$$\begin{array}{l}H{-}O\\H{-}O\end{array}{>}S{<}\begin{array}{l}O\\O\end{array}$$

Dimetasulfuric acid. (Common sulfuric acid.)



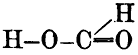
$$\left.\begin{array}{l}H{-}O\\H{-}O\\H{-}O\end{array}\right\rangle C{-}CH_3$$

Ortho-acetic acid.



$$H{-}O{-}C\begin{array}{l}{\diagup}CH_3\\{=}O\end{array}$$

Meta-acetic acid.



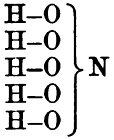
$$H{-}O{-}C\begin{array}{l}{\diagup}H\\{=}O\end{array}$$

Metaformic acid.

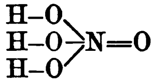
Meta acids contain both linking and saturating oxygen. The number of oxygen atoms must necessarily exceed that of the hydrogen atoms. The removal of a molecule of water leaves an atom of saturating oxygen, so that a monometa acid has one atom of saturating oxygen, a dimeta acid two, etc.

When all the molecules of water are eliminated, a negative or acid oxid is left. Such oxids are called *acid anhydrids; e.g.*, SO_3, sulfuric anhydrid. They may also be given simply the name of oxid, in which case this substance would be called sulfur trioxid.

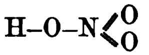
In case the number of basic hydrogen atoms in the acid is odd, the anhydrid must be derived from two molecules of the acid. HNO_3, nitric acid, yields $2HNO_3 - H_2O = N_2O_5$, nitric anhydrid:



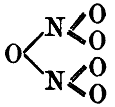
Orthonitric acid.



Monometanitric acid.

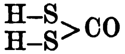


Dimetanitric acid. (Common nitric acid.)



Nitric anhydrid.

In acids containing an analogue of oxygen the meta acids and anhydrids are formed by eliminating molecules of the analogue of water:



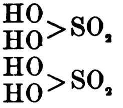
$$\begin{matrix} H{-}S \\ H{-}S \end{matrix}{>}CO$$

Dithiocarbonic acid.

$$S = C = O$$

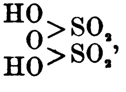
Dithiocarbonic anhydrid. (Carbon oxysulfid.)

Another form of meta acid is found in the so-called *pyro acids:* the original types of these acids were formed by the effect of heat on simpler acids, or salts, which caused molecules of water to split out. The rests so formed then bind themselves together by the remaining atoms of oxygen. Thus:



$$\begin{array}{l} \begin{array}{l}\mathrm{HO}\\ \mathrm{HO}\end{array}\!>\mathrm{SO_2} \\ \begin{array}{l}\mathrm{HO}\\ \mathrm{HO}\end{array}\!>\mathrm{SO_2} \end{array}$$

by the elimination of water yield



$$\begin{array}{l} \mathrm{HO} \\ \;\;\mathrm{O} \\ \mathrm{HO} \end{array}\!\!\begin{array}{l} >\mathrm{SO_2} \\ >\mathrm{SO_2} \end{array}$$

, pyrosulfuric acid.

These acids are also known as *internal anhydrids*, owing to the peculiar relative position and behavior of the linking atom of oxygen. On treatment with water they usually pass back into the simpler acids after the manner of anhydrids; *e.g.:*

$$H_2S_2O_7 + H_2O = 2H_2SO_4.$$

Where there are several acids formed from one element, the use of prefixes is resorted to; *e.g.:*

$H_2S_2O_3$, hyposulfurous acid.
H_2SO_3, sulfurous acid.
H_2SO_4, sulfuric acid.

A *salt* is formed by the replacement of one or more of the hydrogen atoms of an acid by positive (metallic) atoms. Thus, the sodium (Na') salt of nitric acid, HNO_3, is $NaNO_3$; of sulfuric acid, H_2SO_4, is Na_2SO_4. The number of hydrogen atoms replaceable by positive atoms is called the *basicity* of the acid. Thus, nitric acid, HNO_3, has a basicity of one, is monobasic; sulfuric acid, H_2SO_4, is dibasic; arsenous acid, H_3AsO_4, is tribasic, etc.

Salts are named by placing first the name of the metal and then the name of the acid, changing its termination, if " ous " to " ite," and if " ic " to " ate." Thus, the sodium salt of sulfurous acid is Na_2SO_3, sodium sulfite, and of phosphoric acid, Na_3PO_4, sodium phosphate. The same rules apply to the modification of the ending of termination of the positive atom as in the case of binaries. Thus,

$Fe''SO_4$, ferrous sulfate,
$Fe_2^{iv}(SO_4)_3$, ferric sulfate,

the termination " ous " being given to the salt that contains the lesser amount of acid radical.

There are several kinds of salts. When all the hydrogen atoms have been replaced by positive atoms, a *normal salt* is formed; *e.g.:*

H_2SO_4;	K_2SO_4.
Sulfuric acid.	Potassium sulfate.

When only a portion of the hydrogen atoms is replaced by positive atoms, an *acid salt* is obtained; *e.g.:*

H_3PO_4;	HNa_2PO_4.
Phosphoric acid.	Hydrogen disodium phosphate.

An acid salt acts as an acid having a basicity equal to the number of its unreplaced hydrogen atoms.

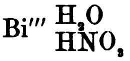
When the hydrogen atoms of an acid are replaced by different positive atoms, a *double salt* is obtained; *e.g.:*

$K'Na'SO_4$;	$(NH_4)Mg''PO_4$.
Potassium sodium sulfate.	Ammonium magnesium phosphate.

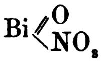
When the hydrogen atoms of an acid are replaced by oxid or hydroxid rests, or by both, *basic salts* are formed. If the H of HNO_3 be substituted by the oxid rest $(Bi'''O'')'$, basic bismuth nitrate, $BiO(NO_3)$, will be formed. An analogous compound can be derived from hydrochloric acid, BiOCl. Basic lead nitrate is a good instance of substitution by a hydroxid rest:

$$(Pb''(OH)')'; \qquad Pb(OH)NO_3.$$

Basic salts are often very complicated, and sometimes difficulty is experienced in assigning them satisfactory formulas. They may also be considered as derived by the replacement of the hydrogen of molecules of water and the acid by the metal. Thus, basic bismuth nitrate may be considered as produced by the replacement of H in water and nitric acid by Bi:

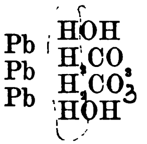


$$Bi''' \begin{matrix} H_2O \\ HNO_3 \end{matrix}$$

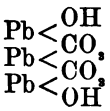


$$Bi \left\langle \begin{matrix} O \\ NO_3 \end{matrix} \right.$$

And white lead:

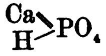


$$\begin{matrix} Pb & HOH \\ & H_2CO_3 \\ Pb & H_2CO_3 \\ Pb & HOH \end{matrix}$$

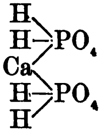


$$\begin{matrix} Pb < & OH \\ & CO_3 \\ Pb < & \\ & CO_3 \\ Pb < & OH \end{matrix}$$

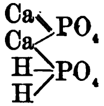
The following formulas represent the possible salts of calcium (Ca'') and phosphoric acid (H_3PO_4), and will serve as an example:



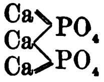
$Ca''HPO_4$



$Ca''H_4(PO_4)_2$



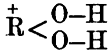
$Ca_2''H_2(PO_4)_2$



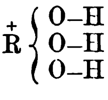
$Ca_3''(PO_4)_2$

A base is a compound that consists of hydrogen bound by oxygen to one or more positive atoms or rests. It is also called a *hydroxid.* Representing an atom or group by $\overset{+}{R}$, the general types of bases may be represented as follows:*

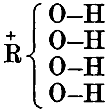
$$\overset{+}{R}\text{–O–H}$$



$$\overset{+}{R} < \begin{matrix}\text{O–H}\\ \text{O–H}\end{matrix}$$



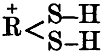
$$\overset{+}{R} \begin{cases}\text{O–H}\\ \text{O–H}\\ \text{O–H}\end{cases}$$



$$\overset{+}{R} \begin{cases}\text{O–H}\\ \text{O–H}\\ \text{O–H}\\ \text{O–H}\end{cases}$$

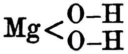
Instead of oxygen atoms other negative atoms may act as links, as, for instance:

$$\overset{+}{R}\text{–S–H}$$



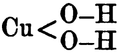
$$\overset{+}{R} < \begin{matrix}\text{S–H}\\ \text{S–H}\end{matrix}$$

As examples of well-known bases, we have—



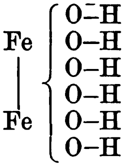
$$\text{Mg} < \begin{matrix}\text{O–H}\\ \text{O–H}\end{matrix}$$

Magnesium hydroxid.



$$\text{Cu} < \begin{matrix}\text{O–H}\\ \text{O–H}\end{matrix}$$

Cupric hydroxid.



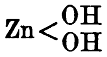
$$\begin{matrix}\text{Fe}\\ |\\ \text{Fe}\end{matrix} \begin{cases}\text{O–H}\\ \text{O–H}\\ \text{O–H}\\ \text{O–H}\\ \text{O–H}\\ \text{O–H}\end{cases}$$

Ferric hydroxid.

Bases are divided, like acids, into ortho and meta. An *ortho base* is one in which all the oxygen has a linking function; *e.g.:*

$$\text{Na–O–H}$$

Sodium hydroxid.



$$\text{Zn} < \begin{matrix}\text{OH}\\ \text{OH}\end{matrix}$$

Zinc hydroxid.

The same rules hold as to the equal number of oxygen and hydrogen atoms, and the equality of the number of

---

* As a matter of convenience in writing the formulas of bases the positive atom is usually placed first. It is more convenient in this way, because less attention to the relative positions of the symbols is then required in writing reactions; *e.g.:*

$$KOH + HNO_3 = KNO_3 + H_2O.$$

hydroxyls with the valence of the positive atoms, or group, as in the case of ortho acids.

Meta bases are derived from ortho bases by splitting off molecules of water:

$Al_2(OH)_6$;	$Al_2O_2(OH)_2$.
Aluminic hydroxid.	Basic aluminic hydroxid.

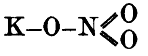
The anhydrid of a base is a metallic oxid:

$Ca(OH)_2$;	CaO.
Calcium hydroxid. (Slaked lime.)	Calcium oxid. (Quicklime.)

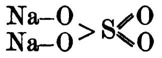
The termination of the name of the positive atom is modified into " ous " and " ic " to indicate the change of valence; *e.g.:*

$Sn''(OH)_2$;	$Sn(OH)_4$.
Stannous hydroxid.	Stannic hydroxid.

A salt may also be considered as formed by the replacement of the H of an hydroxid by a negative oxid. Thus, KNO_3 may be considered as formed by the replacement of H in KOH by $(NO_2)'$. This view, however, does not make the derivation of salts any clearer, and is not always as simple as the other. At best these derivations and relations are but a few of many possible ones. All are correct. The compound is a collection of atoms bound together in a certain way. For the sake of convenience we may consider it as containing groups of atoms, but it will depend on circumstances which atoms we place in the groups. Potassium nitrate and sodium sulfate have the structures—



$$K{-}O{-}N\begin{matrix}\nearrow O\\ \searrow O\end{matrix}$$



$$\begin{matrix}Na{-}O\\ Na{-}O\end{matrix}> S\begin{matrix}\nearrow O\\ \searrow O\end{matrix}$$

We may say that KO is united to NO_2, or that K is united to NO_3; both are correct. So we may say that Na_2O

is united to SO_3, or Na_2 to SO_4, or Na_2O_2 to SO_2; each is correct. In every case the compound consists of a certain collection of atoms united as a definite structure. The grouping of the constituent atoms will differ, depending on the standpoint from which the atomic structure is viewed.

Some bases may play the part of both base and acid, depending on the nature of the substance with which they are treated. Plumbic hydroxid dissolves in potassium hydroxid, forming potassium plumbite, $Pb(OK)_2$, thus acting as an acid; while it also dissolves in nitric acid, forming plumbic nitrate, thus acting as a base.

A ready knowledge of the structure of acids, bases, and salts can be obtained only by practice in writing their formulas. The student is urged to practice the following examples, until he can write them without hesitation.

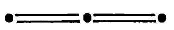
Write ortho acids and all meta acids and anhydrids of Cl', Se'', As''', C^{iv}, N^{v}, S^{vi}.

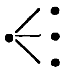
Write all acid, normal and double salts of K', Ba'', Bi''', and Sn^{iv}, with $HClO$, H_2SO_4, H_3PO_4, H_4CO_4.

Write basic salts of Pb'', Bi''', and Sn^{iv}, with H_2O and HNO_3, H_2CO_3 and H_3PO_4, replacing either one or both hydrogen atoms of the H_2O. (See examples under Basic Salts.)

GRAPHS.

If, instead of writing the symbols of the atoms, the atoms are represented by dots, the structural types of the various compounds will appear. These are called "graphs" or "tree-forms" by the English mathematician Cayley. Thus,

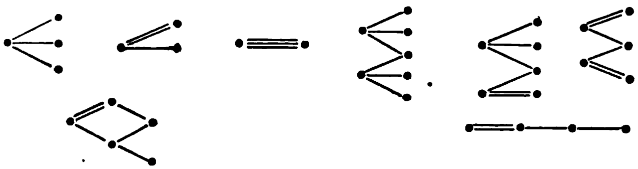




will represent the typical structure of CO_2, SnS_2, LiO_2, NH_3, $BiCl_3$.

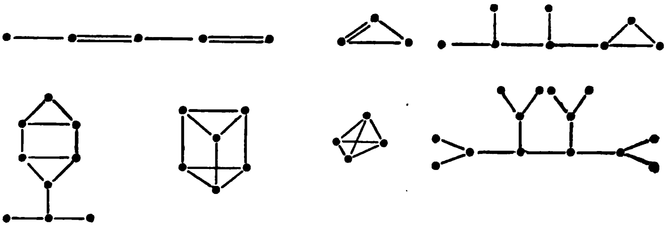
While combinations may be written between any two elements, only a limited number of such combinations are found to be actually possible. The student's advance in chemistry is quite well marked by his increasing ability to infer whether a particular combination is likely to exist or not.

Practice in writing graphs is also valuable, especially in demonstrating that while the combinations of the elements seem unlimited, the compounds are built up on a limited number of skeletons or graphs. Even in organic chemistry, where the combinations seem unlimited, the graphs of many widely differing substances will be found to be identical. In some instances the student may work out graphs to which there are no known compounds to correspond. Thus, the graphs of a triad combined with a monad, diad, and triad may be represented—



etc.

The preceding forms represent compounds in which the chemism of each atom is entirely employed in binding dissimilar atoms. If a portion of the chemism is employed in binding similar atoms, the number of possible forms at once very greatly increases:



The study of graphs becomes particularly interesting in organic chemistry, in which branch the graphs of compounds become much more intricate than in inorganic chemistry.

STOICHIOMETRICAL CALCULATIONS.

WEIGHT, VOLUME, AND SPECIFIC GRAVITY IN AMERICAN MEASURES.

The student accustomed to the metric system is often at loss to convert rapidly into American measures. The following hints have been found valuable in teaching stoichiometry. The specific gravity of a liquid or solid * is the relation between the weight of a certain volume of the substance and the weight of an equal volume of some other substance which is taken as unity. Water is the accepted unit of specific gravity for liquids and solids.

A cubic centimeter of water at 4° C. and 760^{mm} weighs one gram. A cubic-centimeter of sulfuric acid, weighed under the same conditions, is 1.84 grams. The specific gravity of sulfuric acid is, therefore, 1.84. The figure, then, that represents the specific gravity of a liquid or solid indicates how much heavier or lighter than water the substance is.

Let W = weight of substance in grams;
V = volume of substance in cubic centimeters;
Sp. Gr. = the specific gravity of the substances.

Then we have

$$\text{(I)}\quad W = V \times \text{Sp. Gr.}$$

$$\text{(II)}\quad V = \frac{W}{\text{Sp. Gr.}} \qquad \text{(III)}\quad \text{Sp. Gr.} = \frac{W}{V}.$$

---

* For specific gravity of gases see Cooke's Chemical Philosophy, page 2.

(*1*) Sulfuric acid has a specific gravity of 1.84. What is the weight of 40 liters of it? Answer: 73.6 kilograms.

(*2*) 93 liters of oil weigh 81 kilos. What is the specific gravity of the oil? Answer: 0.87.

(*3*) 589 kilos of HCl of a Sp. Gr. of 1.18 occupy what volume (temperature and pressure not taken into account)? Answer: 499.1 liters.

It is to be observed that the relation between the units represented by W and V must be the correct one. If the weight is taken in grams, the volume will be in cubic centimeters; if in kilograms, the volume will be in liters.

While in the French measures the conversion of weight into volume is simple, since the kilogram of water is a liter of water, in our English and American measures a complication is introduced by the necessity to convert gallons into pounds, or *vice versa*, and between these units there is no simple relation. To adapt our formula to the American weights and measures we insert in the term V (volume) the weight of a standard volume of water. The weight of a cubic foot or of a gallon of water may be taken; but, whichever is taken, the volume must be in the same unit.

When gallons are used, the calculations are as follows:

One American gallon of water (231 cubic inches) weighs 8.33 pounds; hence $W = 8.33 \times V \times Sp.\ Gr.$

It is to be particularly noted here that the weight of the American gallon (231 cubic inches) is used, and *not* that of the English gallon (277¼ cubic inches, 10 pounds). Care must be taken, in using figures taken from English books, not to fall into this error, for it is a very common one.

(*4*) What is the weight of 250 gallons of aqua ammonia of a specific gravity of 0.92?

$$W = 8.33 \times 250 \times 0.92 = 1915.9 \text{ pounds.}$$

(*5*) 250 pounds of nitric acid of a specific gravity of 1.19 make how many gallons?

$$V = \frac{W}{8.33 \times Sp.\ Gr.} = \frac{250}{8.33 \times 1.19} = 25.2 \text{ gallons.}$$

(*6*) 18 gallons of a liquid weigh 178 pounds. What is its specific gravity?

$$Sp.\ Gr. = \frac{W}{8.33 \times V} = \frac{178}{8.33 \times 18} = 1.19.$$

The calculation made in cubic feet is similar. The weight of a cubic foot of water is 62.4 pounds; hence

$$W = 62.4 \times V \times Sp.\ Gr.$$

(7) What is the weight of 12 cubic feet of a blue vitriol solution of a specific gravity of 1.2?

$$W = 62.4 \times 12 \times 1.2 = 898.5 \text{ pounds.}$$

WATER FACTORS.

$$1 \text{ U. S. gallon} = \begin{cases} \text{231 cubic inches,} \\ \text{0.13369 cubic foot,} \\ \text{8.3311 lbs. (distilled water),} \\ \text{133.3 ounces avoirdupois,} \\ 8\tfrac{1}{3} \text{ lbs. roughly,} \\ \text{3.78 liters.} \end{cases}$$

$$1 \text{ cubic foot} = \begin{cases} \text{62.425 lbs. at 4°C. (maximum density),} \\ \text{62.418 lbs. at 0° (freezing-point),} \\ \text{62.355 lbs. at 16.6° (62° F.) (standard} \\ \quad \text{temperature),} \\ \text{59.64 lbs. at 100° (boiling-point),} \\ \text{57.5 lbs. of ice,} \\ \text{7.485 U. S. gallons,} \\ \text{28.3 liters.} \end{cases}$$

1 pound = 27.7 cubic inches.

$$\text{1 cubic inch} = \left\{\begin{array}{l}\text{0.03612 pound,}\\ \text{252.7 grams,}\\ \text{16.38 cubic centimeters.}\end{array}\right.$$

$$\text{1 liter} = \left\{\begin{array}{l}\text{0.35 cubic feet,}\\ \text{0.26 U. S. gallon,}\\ \text{2.1 pints.}\end{array}\right.$$

1 minim = 0.06 cubic centimeters.

$$\text{1 cubic centimeter} = \left\{\begin{array}{l}\text{0.06 cubic inch,}\\ \text{16.23 minims,}\\ \text{0.034 fluid ounce.}\end{array}\right.$$

1 fluid ounce = 29.57 cubic centimeters.
1 pint = 473.1 cubic centimeters.
1 pound avoir. = 7000 grains.
1 pound Troy and apoth. = 5760 grains.
1 grain per gallon = 17.12 milligrams per liter.
1 milligram per liter = 0.058318 grains per gallon.
1 fluid dram (apoth.) = 3.7 cubic centimeters.

A column of water 1 inch square and 2.31 feet high weighs one pound.

A column of water 1 inch square and 1 foot high weighs 0.433 pound.

A column of water 33.947 feet high equals the pressure of the atmosphere at sea-level.

One pound per square inch equals a column of water 2.31 feet in height.

0.433 pound per square inch equals a column of water one foot in height.

The latent heat of water is 79 thermal units, of steam is 536 thermal units.

VOLUME AND WEIGHT OF GASES.

The use of the two-volume unit in chemical calculations is frequently omitted in English and American text-books. It deserves attention, however, for it simplifies many calculations involving volumes and is more useful than the crith.

Experiment proves that the molecular weight of a true gas, when taken in grams (0° and 760^{mm}) (gram-molecule), occupies in all cases 22.32 liters. Or, what is the same thing, the weight in grams of 22.32 liters of a normal gas equals the number that expresses the molecular weight of the gas.

2	grams of	hydrogen	($H_2 = 2$)	occupy	22.32	liters.
32	"	oxygen	($O_2 = 32$)	"	22.32	"
28	"	nitrogen	($N_2 = 28$)	"	22.32	"
17	"	ammonia	($NH_3 = 17$)	"	22.32	"
44	"	carbon dioxide	($CO_2 = 44$)	"	22.32	"

The volume, 22.32, is called the "two volumes," or the "two-vol," and is expressed by the symbol □□. 22.3 may be used in cases where the greatest accuracy is not required. Since the molecular weight of a gas in grams occupies in all cases 22.32 liters, then the weight of a liter of gas will be equal to its molecular weight divided by 22.32. The volume occupied by a gram of any gas will equal 22.32 liters divided by its molecular weight. Hence to find the mass in grams of any volume of a gas multiply its molecular weight by the number of liters of it, and divide the product by 22.32. Or, to find the volume in liters of any gas, multiply the number of grams of it by 22.32 and divide the product by its molecular weight. The following proportion gives all the cases:

W = weight of the gas in grams.
V = volume of the gas in liters.
M = molecular weight of the gas.

$\square\square$ = 22.32, the number of liters occupied by M grams of the gas.

$$\square\square : V :: M : W.$$

$$\text{(I)}\ \square\square = \frac{VM}{W}. \qquad \text{(II)}\ V = \frac{\square\square\, W}{M}.$$

$$\text{(III)}\ M = \frac{\square\square\, W}{V}. \qquad \text{(IV)}\ W = \frac{VM}{\square\square}.$$

(*8*) What is the weight of 250 liters of chlorin?

$$W = \frac{250 \times 71}{22.32} = 795.2 \text{ grams.}$$

(*9*) What is the volume of 225 grams of hydrogen sulfid?

$$V = \frac{22.32 \times 225}{34} = 147.7 \text{ liters.}$$

(*10*) 52 liters of methane weigh 37.27 grams at 0° and 760^{mm}. What is its molecular weight?

$$M = \frac{22.32 \times 37.27}{52} = 16.$$

(*11*) How much oxygen can be produced from 40 grams of potassium chlorate?*

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* In this and in the next example the molecular weight of the substance producing the gas is substituted for M.

(26) $$2KClO_3 = 2KCl + 3O_2(\square\square).$$

$$V = \frac{3 \times 22.32 \times 40}{2 \times 122.6} = 109.23 \text{ liters.}$$

(*12*) How much marble will be required to yield 150 liters of carbon dioxid?

(27) $$CaCO_3 + 2HCl = CaCl_2 + CO_2(\square\square) + H_2O.$$

$$W = \frac{150 \times 100}{22.32} = 672.04 \text{ grams.}$$

MOLECULAR AND ATOMIC RELATIONS.

Many problems in stoichiometry are easily solved if the molecular and atomic relations, both of weight and valence, are fully understood, and in this way considerable time and vexation may be saved. As in all other subjects, practice is here invaluable, for it is only by practice that the relations between substances may be readily observed.

As a molecular weight expresses "two volumes" of the gas (0°, 760^{mm}), it is easy to find the volume of a gas when the volume of another gas is given.*

(*13*) When 20 liters of chlorin unite with hydrogen, what volume of hydrochloric acid gas is formed?

(28) $$Cl_2 + H_2 = 2HCl.$$

$$\square\square \quad \square\square = 2\square\square.$$

Solution.—As two volumes of chlorin form twice two-vols of hydrogen chlorid, 20 liters of chlorin form 20 × 2 = 40 liters of HCl gas.

(*14*) What volume of steam at 300° C. is formed when 10 liters of hydrogen at 15° C. are burnt?

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* Compare Lupton's Chemical Arithmetic, page 41.

(29)
$$H_2 + O = H_2O.$$
$$\square\square \quad \square = \square\square.$$

Solution.—If the temperatures were the same, the volumes of the hydrogen and the steam would be the same. Correcting for temperature, we have

$$V = \frac{10(273 + 300)}{273 + 15} = 19.895 \text{ liters.}$$

(*15*) How much oxygen is required to burn one liter of carbon disulfid gas?

(30)
$$CS_2 + 3O_2 = CO_2 + 2SO_2.$$
$$\square\square \quad 3\square\square = \square\square + 2\square\square.$$

Solution.—It is evident that three liters are required. Further, one liter of carbon dioxid and two liters of sulfur dioxid are produced.

(*16*) How much alcohol gas is required to give two cubic meters of steam?

(31)
$$C_2H_6O + 3O_2 = 2CO_2 + 3H_2O.$$
$$\square\square \quad 3\square\square \quad 2\square\square \quad 3\square\square.$$

Solution.—Three cubic meters of steam require one cubic meter of alcohol gas. Hence to produce two cubic meters of steam $\frac{2}{3}CM^3$ of alcohol gas will be required.

(*17*) From the residue obtained from the production of marsh gas from sodium acetate and sodium hydroxid there were obtained on the addition of an acid twelve grams of carbon dioxid. How many liters of methane had been produced from the mixture?

Solution.

(32) $NaC_2H_3O_2 + NaOH = Na_2CO_3 + CH_4(\square\square).$

(33) $Na_2CO_3 + 2HCl = 2NaCl + H_2O + CO_2(\square\square).$

The volumes of carbon dioxid and methane are the same. The volume of carbon dioxid produced is

$$V = \frac{\square\square \times W}{M} = \frac{22.34 \times 12}{44} = 6.09 \text{ liters,}$$

and the volume of methane must be the same.

In cases where there are a number of chemical actions involved it is, as a rule, only necessary to establish the molecular or atomic relation between the substance given and the substance required; *e.g.:*

(*18*) Chlorin* is evolved from 100 grams of potassium chlorate by means of hydrochloric acid. This chlorin is lead over an excess of phosphorus and the phosphorus trichlorid, which results, is decomposed by an excess of water. How much potassium hydroxid will be required to neutralize the phosphorous acid thus formed ?

Solution.

$$\text{(I) } KClO_3 + 6HCl = KCl + 3H_2O + 3Cl_2. \tag{34}$$

$$\text{(II) } 6Cl_2 + P_4 = 4PCl_3. \tag{35}$$

$$\text{(III) } PCl_3 + 3H_2O = H_3PO_3 + 3HCl. \tag{36}$$

$$\text{(IV) } H_3PO_3 + 2KOH = K_2HPO_3 + 2H_2O. \tag{37}$$

In order to make the amounts of chlorin, phosphorus trichlorid, and phosphorous acid the same in all the equations, No. I must be multiplied by 2, and Nos. III and IV by 4. Then it is at once evident that by the use of $2KClO_3$ (2×122.5) $8KOH$ (8×56) will be required for the neutralization. Hence for the neutralization of 100 grams of potassium chlorate we have

$$\frac{100 \times 8 \times 56}{2 \times 122.5} = 182.86 \text{ grams KOH.}$$

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* This example is taken from Boeke, Sammlung Stoichiometrischen Aufgaben,

SPECIFIC GRAVITY OF GASES.

Sp. Gr. = water standard.
𝕾𝖕. 𝕲𝖗. = air standard.
Sp. Gr. = hydrogen standard.

$$W = V \times \text{Sp. Gr.}$$
$$W = V \times \text{Sp. Gr.} \times 0.0000896.$$

One liter of air weighs 1.293187 g.
𝕾𝖕. 𝕲𝖗.: Sp. Gr.: : 1.2932 : 0.0896.

$$\textbf{𝕾𝖕. 𝕲𝖗.} = \text{Sp. Gr.} \times 14.42.$$
$$\text{Sp. Gr.} = \textbf{𝕾𝖕. 𝕲𝖗.} \times 0.06929.$$

The weight of a volume of a gas in hydrogen units will be as many times heavier or greater than the weight of the same volume of air units as the weight of a liter of air divided by the weight of a liter of hydrogen.

CALCULATIONS INVOLVING A SERIES OF REACTIONS.

When the amount of a substance is to be computed that shall produce a given weight of another substance, and the production involves several steps, it is necessary to compare only the amounts in the final and last equations, after having brought them to atomic balance.

Thus, in the series

(38) $\mathrm{Fe + H_2SO_4 = FeSO_4 + H_2}$
(39) $\mathrm{FeSO_4 + 2NaOH = Fe(OH)_2 + Na_2SO_4}$
(40) $\mathrm{Fe(OH)_2 + 2HNO_3 = Fe(NO_3)_2 + 2HO_2}$
(41) $\mathrm{6Fe(NO_3)_2 + 6HNO_3 = 3Fe_2(NO_3)_6 + 4H_2O}$

six atoms of iron are demanded in the last equation; hence the other reactions must be multiplied by six to bring them into atomic balance:

(42) $6Fe + 6H_2SO_4 = 6FeSO_4 + 6H_2$
(43) $6FeSO_4 + 12NaOH = 6Fe(OH)_2 + 6Na_2SO_4$
(44) $6Fe(OH)_2 + 12HNO_3 = 6Fe(NO_3)_2 + 12H_2O$
(45) $6Fe(NO_3)_2 + 6HNO_3 = 3Fe_2(NO_3)_6 + 4H_2O$.

(*19*) If it were asked how much iron would be required to produce ten grams of ferric nitrate by this process, the proportion would be

$$3Fe_2(NO_3)_6 : 6Fe :: 10 : x,$$

or

$$Fe_2(NO_3)_6 : 2Fe :: 10 : x.$$

(*20*) How much nitric acid would be required to produce ten grams of ferric nitrate by this process?

$$3Fe_2(NO_3)_6 : 18HNO_3 :: 10 : x.$$

(*21*) How much hydrochloric acid 30 per cent strong will be required to produce calcium nitrate from calcium sulfate 80 per cent strong by the following process?—

(46) $CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$
(47) $CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$.

DILUTION OF VOLUMETRIC SOLUTIONS.

(*22*) It is required to make a solution of sulfuric acid that shall neutralize the same volume of a solution of sodium hydroxid. Experiment shows that 1 c.c. of the acid equals 1.6 c.c. of the alkali. How much water must be added to the acid to make it volumetrically equal to the alkali? It is evident that to each cubic centimeter of the acid 0.6 c.c.

of water must be added. Then 1.6 c.c. of acid will neutralize 1.6 c.c. of the alkali, or 1 c.c. acid will equal 1 c.c. alkali.

(*23*) It is required to make a solution of potassium permanganate of which 1 c.c. shall equal 0.001 gram of iron. Experiment shows that 1 c.c. of the permanganate equals 0.0018 g. of iron. How much water shall be added to the permanganate?

If to each cubic centimeter 0.8 c.c. of water are added, then 1 c.c. will equal 0.001 g. iron.

$$1.8 \text{ c.c.} = 0.0018 \text{ g. Fe.}$$

$$1 \text{ c.c.} = 0.001 \text{ g. Fe.}$$

(*24*) In another preparation of the foregoing experiment shows that 1 c.c. of the acid equals 1.8 c.c. of the alkali. How much alkali 98 per cent strong must be added to make the solutions volumetrically equal if 1 c.c. of the acid contains 0.1 g. of H_2SO_4?

$$1 \text{ c.c. } H_2SO_4 = 0.1 \text{ g. } H_2SO_4$$

$$H_2SO_4 : 2NaOH :: 0.1 : 0.0816$$

$$1.8 \text{ c.c.} = 0.0816 \text{ NaOH}$$

$$1 \text{ c.c.} = 0.0450$$

$$0.0816 - 0.0450 = 0.0366.$$

To each cubic centimeter of the alkali 0.0366 NaOH must be added, or at 98 per cent 0.0373 g.

DILUTION BY PERCENTAGE STRENGTH.*

(*25*) How much water is necessary to reduce 1000 kilos of 92 per cent alcohol to 85 per cent?

$$100:92::1000:920.$$

That is, if 100 parts contain 92 parts, 1000 parts will contain 920 parts, of absolute alcohol.

If 100 parts contain 85 parts of absolute alcohol, 920 kilos of absolute alcohol must be contained in $\frac{100}{85}$ of 92.

$$85:100::920:x.$$

$$x = 1082.4.$$

Therefore 1000 kilos of 95 per cent alcohol will produce 1082.4 kilos of 85 per cent alcohol. Hence 1082.4 − 920 kilos = 162.40 kilos, which represents the weight of water that must be added.

(*26*) How much water is necessary to reduce 500 gallons of 50 per cent sulfuric acid to 45 per cent?

(*27*) How many gallons of water must be evaporated from 250 gallons of 50 per cent sulfuric acid to raise the gravity to 58 per cent?

DILUTION OF LIQUIDS BY SPECIFIC GRAVITY.

FROM A HIGHER SPECIFIC GRAVITY TO A LOWER.

(*28*) How much water is required to reduce 1 liter of a liquid of 1.35 Sp. Gr. to 1.30 Sp. Gr.?

Add to 1 liter of the liquid of 1.35 Sp. Gr. x liters of water to bring the liquid to the Sp. Gr. of 1.30. The volume of the liquid will then be $1 + x$ liters, and its specific gravity will be 1.30.

---

* For this and the following methods I am indebted to Fennel's Principles of General Pharmacy, page 42.

$$W = V \times Sp.\ Gr.$$

$$W = (1 + x) \times 1.30.$$

At first the weight of the liquid would be

$$1.35 \times 1 = 1.35 \text{ liters.}$$

The weight of x liters of water is x kilos. Hence the weight of the diluted liquid is $1.35 + x$ kilos. Therefore

$$1.35 + x = (1 + x)\,1.30,$$

since both sides of the equation represent the diluted liquid. By elimination and substitution

$$1.35 + x = 1.30 + 1.30x$$

$$1.35 - 1.30 = 1.30x - x$$

$$0.05 = 0.30x$$

$$x = \frac{0.05}{0.30} = 0.166 \text{ liters.}$$

$\frac{166}{1000}$, or 166 c.c. (grams) of water must be added.

RULE. To reduce the specific gravity of a liquid heavier than water by the addition of water.

(1) Subtract the number giving the lower *Sp. Gr.* from the number giving the higher one, and call it A.

(2) Subtract the number one from the number giving the lower *Sp. Gr.*, and call it B.

(3) Divide A by B, and call quotient C.

The quotient obtained expresses the number of volumes, or a fraction thereof, of water to be added to each of the volumes of the liquid to be diluted.

$$\begin{array}{ll} 1.35 & \text{higher } Sp.\ Gr. \\ 1.30 & \text{lower } Sp.\ Gr. \\ \hline 0.05 = A. & \end{array}$$

$$\begin{array}{ll} 1.30 & \text{lower } Sp.\ Gr. \\ 1.00 & \\ \hline 0.30 = B. & \end{array}$$

$$\frac{A}{B} = C = \frac{0.5}{0.30}$$

$$C = 0.166.$$

To each volume of the original liquid (1 liter, or 1000 c.c.) $\frac{166}{1000}$ of the volume are to be added.

$$1000 \times \frac{66}{1000} = 166 \text{ c.c.}$$

FROM A LOWER SPECIFIC GRAVITY TO A HIGHER.

(*29*) How much water is necessary to increase the *Sp. Gr.* of 12 liters of a liquid of 0.89 *Sp. Gr.* to 0.95 *Sp. Gr.?*

To 1 liter at 0.89 *Sp. Gr.* add x liters of water to bring it to 0.95. After the addition of the water the volume of the liquid will be $1 + x$ liters of a *Sp. Gr.* of 0.95. The weight will be $(1 + x)\,0.95$. The weight of one liter of liquid at 0.89 will be 0.89 kilos.

$$0.89 + x = (1 + x)\,0.95$$

$$0.89 + x = 0.95 + 0.95x$$

$$x - 0.95x = 0.95 - 0.89$$

$$0.05x = 0.06$$

$$x = \frac{0.06}{0.05} = 1.2$$

Rule. (1) Subtract the number giving the lower *Sp. Gr.* from the number giving the higher, and call it A'.

(2) Subtract the number giving the higher *Sp. Gr.* from the number one, and call it B'.

(3) Divide A' by B', and call the quotient C'.

The quotient thus obtained expresses the number of volumes, or fractions thereof, which are to be added to each of the volume of the liquid of which the *Sp. Gr.* is to be increased.

$$\begin{array}{ll} 0.95 & \text{high } Sp.\ Gr. \\ 0.89 & \text{low } Sp.\ Gr. \\ \hline 0.06 = A'. & \end{array}$$

$$\begin{array}{ll} 1.00 & \\ 0.95 & \text{high } Sp.\ Gr. \\ \hline 0.05 = B'. & \end{array}$$

$$\frac{A'}{B'} = C' = 1.2.$$

That is, 1.2 times the original volume must be added.

(*30*) How many gallons of water must be added to a tank containing 400 cubic feet of ammonia liquor of 0.92 Sp. Gr. to bring the gravity to 0.97 ?

CERTAIN CHEMICAL REACTIONS.

There are certain chemical reactions that always give more or less trouble to beginners. These usually take place in several steps or involve changes in valence. Some of the more common and typical ones will be considered.

A clearer understanding of the mechanism of reactions involving several steps is gained by writing out the steps and, after eliminating substances equal on both sides, adding up the remaining substances. In this way a single equation, which represents the result of all the steps, is easily obtained, and the student gets some insight into the changes which take place. The single equations representing complicated chemical changes which are found in many text-books convey little or no meaning to the beginner other than the state of the case before and after the reaction. There is no clue to the mechanism of the reaction. The student does not gain a practical working knowledge of reactions and is not able to work them out satisfactorily. Reaction-writing when properly taught is an incentive to experimental investigation.

The method of elimination and addition is common among laboratory-workers. It was often used by the late Prof. A. W. Hofmann in instructing students.

The solution of copper in sulfuric acid is attended with the evolution of sulfur dioxid:

$$\begin{array}{ll} (48) & Cu + H_2SO_4 = CuSO_4 + \mathit{2H} \\ (49) & H_2SO_4 + \mathit{2H} = SO_2 + 2H_2O \\ \hline (50) & Cu + 2H_2SO_4 = CuSO_4 + SO_2 + 2H_2O. \end{array}$$

The formulas printed in italics represent substances produced in one step and consumed in another. In blackboard practice these common symbols and figures should be struck out with cancellation-sign or written with a colored crayon. When the whole of a number is not consumed, it is best to cancel the figure and write what is left above it. In the following examples the figures and symbols canceled will be represented by italics.

In the case of the solution of copper in sulfuric acid the reduction sometimes proceeds further, involving the sulfur dioxid:

$$\begin{array}{ll}
(51) & \mathrm{H_2SO_4} + 2H = SO_2 + \mathrm{2H_2O} \\
(52) & SO_2 + 6H = \mathrm{H_2S} + \mathrm{2H_2O} \\
(53) & \mathrm{4Fe} + \mathrm{4H_2SO_4} = \mathrm{4FeSO_4} + 8H \\
\hline
(54) & \mathrm{4Fe} + \mathrm{5H_2SO_4} = \mathrm{4FeSO_4} + \mathrm{H_2S} + \mathrm{4H_2O}.
\end{array}$$

It is to be observed that elements which are set free in one step and consumed in another are written as free atoms, and not as molecules, because they are assumed to react on the other substances at the instant they are liberated, and before they can unite to form molecules. Hydrogen gas, H_2, can be passed through sulfuric acid (as in drying the gas) without affecting it, but if set free under the proper conditions in the acid the foregoing reactions take place.

From reactions 51 and 52 it is seen that eight atoms of hydrogen are required for the reduction of H_2SO_4 and SO_2. The reaction

$$(55) \qquad \mathrm{Fe + H_2SO_4 = FeSO_4 + 2H}$$

is therefore multiplied all through by four in order to produce the required amount of hydrogen.

The nitric acid reactions are always a stumbling-block to students, and the mere memorization of their numerous equations does not enable the student to understand or utilize them. They involve one or more of the following types:

$$\begin{array}{ll}
(56) & \mathrm{2HNO_3 + 2H = N_2O_4 + 2H_2O}. \\
(57) & \mathrm{2HNO_3 + 6H = N_2O_3 + 4H_2O}. \\
(58) & \mathrm{2HNO_3 + 8H = N_2O + 5H_2O}. \\
(59) & \mathrm{2HNO_3 + 8H = (NH_4)NO_3 + 3H_2O}.
\end{array}$$

The formulas of the nitrogen di- and tetroxids are written N_2O_2 and N_2O_4 to accord with the series. They correspond to these formulas only at very low temperatures. In the gaseous state they have the formulas NO and NO_2, or half those given. Nitrous anhydrid, N_2O_3, exists only at a very low temperature. In the gaseous state it breaks into NO and NO_2. It will therefore not be considered among the reduction-products of nitric acid.

In quizzing, especially with large classes, I can see no objection to speaking of four atoms of H, or even of four H's, instead of four atoms of hydrogen. The practice may be reprehensible, as some writers insist, but as a matter of fact it saves time, and it is also the usual parlance of chemists. It is just as well, however, not to overdo it.

$$\begin{array}{ll}
(60) & \mathrm{2HNO_3} + \mathit{6H} = \mathrm{N_2O_2 + 4H_2O} \\
(61) & \mathrm{3Cu + 6HNO_3 = 3Cu(NO_3)_2} + \mathit{6H} \\
\hline
(62) & \mathrm{3Cu + 8HNO_3 = 3Cu(NO_3)_2 + N_2O_2 + 4H_2O.}
\end{array}$$

$$\begin{array}{ll}
(63) & \mathrm{2HNO_3} + \mathit{8H} = \mathrm{N_2O + 5H_2O} \\
(64) & \mathrm{4Zn + 8HNO_3 = 4Zn(NO_3)_2} + \mathit{8H} \\
\hline
(65) & \mathrm{4Zn + 10HNO_3 = 4Zn(NO_3)_2 + N_2O + 5H_2O.}
\end{array}$$

The oxidation of sulfids by nitric acid often proceeds to the oxidation of the liberated sulfur to sulfuric acid, and the interaction of the sulfuric acid thus formed on the nitrates produced, especially when the sulfate of the metal is an insoluble substance.

$$\begin{array}{ll}
(66) & \mathrm{2HNO_3} + \mathit{3H_2S} = \mathrm{N_2O_2 + 4H_2O} + \mathit{S} \\
(67) & \mathrm{3PbS + 6HNO_3 = 2}\mathit{3}\mathrm{Pb(NO_3)_2} + \mathit{3H_2S} \\
(68) & \mathit{S + H_2O + 3O} = \mathrm{H_2SO_4} \\
(69) & \mathit{2HNO_3} = \mathrm{N_2O_2 + H_2O} + \mathit{3O} \\
(70) & \mathit{Pb(NO_3)_2 + H_2SO_4} = \mathrm{Pb(SO_4)} + \mathit{2HNO_3}. \\
\hline
(71) & \mathrm{3PbS + 8HNO_3 = 2N_2O_2 + 4H_2O + PbSO_4 + 2Pb(NO_3)_2.}
\end{array}$$

Oxidation of ferrous chlorid to ferric chlorid by nitric acid:

$$\mathrm{6FeCl_2} + \mathit{6Cl} = \mathrm{3Fe_2Cl_6} \tag{72}$$
$$\mathrm{6HCl} + \mathit{3O} = \mathrm{3H_2O} + \mathit{6Cl} \tag{73}$$
$$\mathrm{2HNO_3} = \mathrm{N_2O_2} + \mathrm{H_2O} + \mathit{3O} \tag{74}$$
$$\mathrm{6FeCl_2} + \mathrm{6HCl} + \mathrm{2HNO_3} = \mathrm{3Fe_2Cl_6} + \mathrm{4H_2O} + \mathrm{N_2O_2}. \tag{75}$$

The first writing of this reaction is

$$\mathrm{2FeCl_2} + \mathrm{2Cl} = \mathrm{Fe_2Cl_6} \tag{76}$$
$$\mathrm{2HCl} + \mathrm{O} = \mathrm{H_2O} + \mathrm{2Cl} \tag{77}$$
$$\mathrm{2HNO_3} = \mathrm{N_2O} + \mathrm{H_2O} + \mathrm{3O}. \tag{78}$$

On writing the third equation it is seen that the first two equations must be multiplied by three to balance them against 3O.

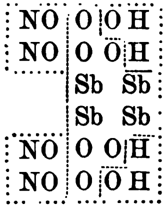
It must be thoroughly understood, however, that many of these steps in reactions do not take place alone. Thus, the reaction

$$\mathrm{2HNO_3} = \mathrm{N_2O_2} + \mathrm{H_2O} + \mathrm{3O} \tag{79}$$

will not take place unless a substance is present that will unite with the oxygen. The equation might be taken to represent the state of affairs at that minute period of time during which the oxygen has been freed from the nitric acid and before it has united with the other element to form a new compound. If antimony, for instance, is present, the reaction will take place:

$$\mathrm{Sb_4} + \mathit{6O} = \mathrm{Sb_4O_6} \tag{80}$$
$$\mathrm{4HNO_3} = \mathrm{N_2O_2} + \mathrm{2H_2O} + \mathit{6O} \tag{81}$$
$$\mathrm{Sb_4} + \mathrm{4HNO_3} = \mathrm{Sb_4O_6} + \mathrm{N_2O_2} + \mathrm{2H_2O}. \tag{82}$$

The change may be expressed graphically:



The reaction

$$H_2SO_3 + H_2O = H_2SO_4 + 2H \tag{83}$$

does not take place on contact of the two substances, but if iodin is present it takes place:

$$H_2SO_3 + \begin{array}{|c|c|} H & H \\ I & I \end{array}\ O = H_2SO_4 + 2HI. \tag{84}$$

For the sake of convenience, then, the reaction may be considered as taking place in two steps:

$$\begin{array}{ll} (85) & H_2SO_3 + H_2O = H_2SO_4 + \mathit{2H} \\ (86) & I_2 + \mathit{2H} = 2HI \\ \hline (87) & H_2SO_3 + I_2 + H_2O = H_2SO_4 + 2HI. \end{array}$$

The following reactions which often give trouble to the student will be found to be easy enough if dissected so that the steps appear clearly.

SULFUROUS ACID.

Reduction of mercuric chlorid by sulfurous acid:

$$\begin{array}{ll}
(88) & 2HgCl_2 + 2H = Hg_2Cl_2 + 2HCl \\
(89) & H_2SO_3 + H_2O = H_2SO_4 + 2H \\
\hline
(90) & 2HgCl_2 + H_2SO_3 + H_2O = H_2SO_4 + Hg_2Cl_2 + 2HCl.
\end{array}$$

Reduction of ferric chlorid by sulfurous acid:

$$\begin{array}{ll}
(91) & Fe_2Cl_6 + 2H = 2FeCl_2 + 2HCl \\
(92) & H_2SO_3 + H_2O = H_2SO_4 + 2H \\
\hline
(93) & Fe_2Cl_6 + H_2SO_3 + H_2O = 2FeCl_2 + H_2SO_4 + 2HCl.
\end{array}$$

As an oxidizing agent the sulfurous acid may be decomposed, in which case it acts as an oxidizing agent:

$$\begin{array}{ll}
(94) & 6SnCl_2 + 8\ 12\ HCl = 6SnCl_4 + 12H. \\
(95) & 2H_2SO_3 + 12H = 2H_2S + 6H_2O. \\
(96) & SnCl_4 + 2H_2S = SnS_2 + 4HCl. \\
\hline
(97) & 6SnCl_2 + 8HCl + 2H_2SO_3 = 5SnCl_4 + SnS_2 + 6H_2O.
\end{array}$$

When there is any doubt about a reaction, an attempt should always be made to work out the mechanism of it, for the reaction should be more to the student than a mere arithmetical equation that balances.

Reduction of sulfurous acid by copper in the presence of hydrochloric acid:

$$\begin{array}{ll}
(98) & H_2SO_3 + 4HCl = S + 3H_2O + 4Cl \\
(99) & 2Cu + S = Cu_2S \\
(100) & 2Cu + 4Cl = 2CuCl_2 \\
\hline
(101) & 4Cu + H_2SO_3 + 4HCl = Cu_2S + 2CuCl_2 + 3H_2O,
\end{array}$$

Reduction of cupric chlorid by sulfurous acid:

$$\begin{array}{ll}
(102) & 2CuCl_2 = Cu_2Cl_2 + \mathit{2Cl}\\
(103) & \mathit{2Cl} + H_2O = 2HCl + \mathit{O}\\
(104) & H_2SO_3 + \mathit{O} = H_2SO_4\\
\hline
(105) & 2CuCl_2 + H_2SO_3 + H_2O = Cu_2Cl_2 + 2HCl + H_2SO_4.
\end{array}$$

PERMANGANIC ACID.

Potassium permanganate acts as a powerful oxidizer, since it readily parts with its oxygen. On treatment with sulfuric acid permanganic acid, an unstable substance, is produced, so that the reactions may be considered as taking place with it.

Oxidation of ferrous sulfate by permanganic acid:

$$\begin{array}{ll}
(106) & \mathit{2HMnO_4} + 2H_2SO_4 = 2MnSO_4 + 3H_2O + \mathit{5O}\\
(107) & 2KMnO_4 + H_2SO_4 = K_2SO_4 + \mathit{2HMnO_4}\\
(108) & 10FeSO_4 + 5H_2SO_4 = 5Fe_2(SO_4)_3 + \mathit{10H}\\
(109) & \mathit{10H} + \mathit{5O} = 5H_2O\\
\hline
(110) & \left.\begin{array}{l}2KMnO_4 + 8H_2SO_4\\ \quad + 10FeSO_4\end{array}\right\} = \left\{\begin{array}{l}5Fe_2(SO_4)_3 + 2MnSO_4\\ \quad + K_2SO_4 + 8H_2O.\end{array}\right.
\end{array}$$

Oxidation of sulfurous acid by permanganic acid:

$$\begin{array}{ll}
(111) & 2HMnO_4 + \mathit{2H_2SO_4} = 2MnSO_4 + 3H_2O + \mathit{5O}\\
(112) & 5H_2SO_3 + \mathit{5O} = 3\mathit{5}H_2SO_4\\
\hline
(113) & 2HMnO_4 + 5H_2SO_3 = 2MnSO_4 + 3H_2SO_4 + 3H_2O.
\end{array}$$

Or the reaction may be considered as taking place without the addition of sulfuric acid:

$$\begin{array}{ll}
(114) & 2HMnO_4 = \mathit{Mn_2O_2(OH)_2} + \mathit{4O}\\
(115) & 5H_2SO_3 + \mathit{5O} = 3\mathit{5}H_2SO_4\\
(116) & \mathit{Mn_2O_2(OH)_2} + \mathit{2H_2SO_4} = 2MnSO_4 + 3H_2O + \mathit{O}\\
\hline
(117) & 2HMnO_4 + 5H_2SO_3 = 2MnSO_4 + 3H_2SO_4 + 3H_2O.
\end{array}$$

These two equations show that the simplest expression of a reaction does not always throw any light upon the steps involved in it. In these two reactions the same result is obtained by two very different sets of reactions. It is not always entirely correct to express a chemical change by the simplest equation. In equation 111 two molecules of sulfuric acid are consumed in the first step in uniting with the manganese to form manganous sulfate. In the second step five molecules of sulfuric acid are produced. The simplest arithmetical relation is three molecules of sulfuric acid, as shown, but as a fact the two molecules of sulfuric acid on the left side of the first reaction are consumed, and hence do not form a part of the five molecules of sulfuric acid on the right side of the second equation. The proper expression of the real chemical relationship would therefore be:

$$(118) \quad 2HMnO_4 + 5H_2SO_3 + 2H_2SO_4 = 2MnSO_4 + 5H_2SO_4 + 3H_2O.$$

As a rule, however, the simplest arithmetical relation is expressed, as that suffices for stoichiometrical purposes.

Interesting is the reduction of permanganic acid by free atoms of oxygen, as in the case of hydrogen peroxid. This may appear at first sight a paradoxical statement, but as rereduction means the removal of oxygen from a molecule containing it, it does not matter what the element is with which the oxygen combines; and in this case it is oxygen.

$$(119) \quad 2HMnO_4 + H_2SO_4 = 2MnSO_4 + 3H_2O + 5\mathit{O}$$

$$(120) \quad 5H_2O_2 = 5H_2O + 5\mathit{O}$$

$$(121) \quad 5\mathit{O} + 5\mathit{O} = 5O_2$$

$$(122) \quad \left.\begin{matrix} 2HMnO_4 + H_2SO_4 \\ + 5H_2O_2 \end{matrix}\right\} = \left\{\begin{matrix} 2MnSO_4 + 3H_2O \\ + 5H_2O + 5O_2. \end{matrix}\right.$$

Permanganic acid easily liberates the halogens from binary combinations:

$$\begin{array}{lc}
(123) & \mathrm{2HMnO_4 + 4HCl = 2MnCl_2} + \mathit{5O} \\
(124) & \mathrm{10\,HCl} + \mathit{5O} = \mathrm{5Cl_2 + 5H_2O} \\ \hline
(125) & \mathrm{2HMnO_4 + 14HCl = 2MnCl_2 + 5Cl_2 + 6H_2O.}
\end{array}$$

In the absence of a free acid, potassium permanganate acts as an oxidizing agent, but in this case potassium hydroxid and manganic hydroxid are formed:

$$\begin{array}{lc}
(126) & \mathrm{2KMnO_4 + 2H_2O = 2KOH + Mn_2O_2\,(OH)_2} + \mathit{4O} \\
(127) & \mathrm{4C_2H_6O} + \mathit{4O} = \mathrm{4C_2\,H_4O + 4H_2O} \\ \hline
(128) & \mathrm{2KMnO_4 + 4C_2H_6O} = \left\{ \begin{array}{r} \mathrm{2KOH + Mn_2O_2(OH)_2} \\ \mathrm{+ 4C_2H_4O + 2H_2O.} \end{array} \right.
\end{array}$$

HYDROGEN DIOXID.

Hydrogen dioxid is a typical oxidizer, acting by liberating nascent oxygen:

$$(129) \qquad \mathrm{2HCl + H_2O_2 = 2H_2O + Cl_2.}$$

The peroxids act in the same way, hydrogen dioxid being set free by the action of the acid:

$$\begin{array}{lc}
(130) & \mathrm{BaO_2 + 2HCl = BaCl_2 + H_2O_2} \\
(131) & \mathrm{H_2O_2 = H_2O} + \mathit{O} \\
(132) & \mathrm{2HCl} + \mathit{O} = \mathrm{H_2O + Cl_2} \\ \hline
(133) & \mathrm{BaO_2 + 4HCl = BaCl_2 + 2H_2O + Cl_2.}
\end{array}$$

So loosely bound is the second atom of oxygen in hydrogen dioxid that it will bring about some anomalous reactions:

$$(134) \qquad \mathrm{Ag_2O + H_2O_2 = 2Ag + H_2O + 3O_2.}$$

In this case the affinity between the atoms of oxygen is greater than between those of silver and oxygen. Hydrogen dioxid reduces silver oxid. Oxygen *oxidizes* oxygen.

CHROMIC ACID.

Chromic acid, like permanganic acid, acts as a powerful oxidizer when it passes from an acid into a salt of chromium, liberating oxygen, if there is a substance present that is easily oxidized.

Oxidation of hydrochloric acid by chromic acid:

(135) $K_2Cr_2O_7 + \mathit{H_2O} + H_2SO_4 = K_2SO_4 + \mathit{2H_2CrO_4}$

(136) $\mathit{2H_2CrO_4} + 6HCl = Cr_2Cl_6 + 5H_2O + \mathit{3O}$

(137) $\underline{6HCl + \mathit{3O} = 2\,\mathit{3H_2O} + 3Cl_2}$

(138) $\left.\begin{array}{r} K_2Cr_2O_7 + H_2SO_4 + \\ 12HCl \end{array}\right\} = \left\{\begin{array}{l} K_2SO_4 + Cr_2Cl_6 + \\ 5H_2O + 2H_2O + 3Cl. \end{array}\right.$

This reaction often occurs when dissolving substances containing chromates in hydrochloric acid.

Oxidation of a ferrous salt by chromic acid:

(139) $6FeSO_4 + 3H_2SO_4 + \mathit{3O} = 3Fe_2(SO_4)_3 + 3H_2O$

(140) $\underline{2H_2CrO_4 + 3H_2SO_4 = Cr_2(SO_4)_3 + 5H_2O + \mathit{3O}}$

(141) $\left.\begin{array}{r} 6FeSO_4 + 6H_2SO_4 \\ + 2H_2CrO_4 \end{array}\right\} = \left\{\begin{array}{r} 3Fe_2(SO_4)_3 + Cr_2(SO_4)_3 \\ + 8H_2O. \end{array}\right.$

IODIN.

Iodin usually acts as a powerful oxidizing agent, dividing the elements of water with a substance that will take up oxygen, Oxidation of sulfurous acid by iodin:

(142) $I_2 + H_2O = 2HI + \mathit{O}$

(143) $H_2SO_3 + \mathit{O} = H_2SO_4$

(144) $H_2SO_4 + I_2 + H\ O = H_2SO_4 + 2HI.$

Oxidation of an arsenite by iodin:

(145) $Na_3AsO_3 + \mathit{O} = Na_3AsO_4$

(146) $I_2 + H_2O = 2HI + \mathit{O}$

(147) $Na_3AsO_3 + I_2 + H_2O = Na_3AsO_4 + 2HI.$

HYDRIODIC ACID.

Hydriodic acid acts as a strong reducing agent, as it easily breaks into hydrogen and iodin.

Reduction of sulfuric acid by hydriodic acid:

(148) $2HI = \mathit{2H} + I_2$

(149) $H_2SO_4 + \mathit{2H} = 2H_2O + SO_2$

(150) $H_2SO_4 + 2HI = 2H_2O + SO_2 + I_2.$

Reduction of ferrous chlorid by hydriodic acid:

(151) $Fe_2Cl_6 = 2FeCl_2 + \mathit{2Cl}$

(152) $\mathit{2}HI = \mathit{2H} + I_2$

(153) $\mathit{2Cl} + \mathit{2H} = 2HCl$

(154) $Fe_2Cl_6 + 2HI = 2FeCl_2 + 2HCl + I_2.$

ARSENIC ACID.

The conversion of arsenic acid into arsenous acid allows it to be used as an oxidizing agent.

Oxidation of sulfurous acid by arsenic acid:

(155) $H_3AsO_4 = H_3AsO_3 + \mathit{O}$

(156) $H_2SO_3 + \mathit{O} = H_2SO_4$

(157) $H_2SO_3 + H_3AsO_4 = H_3AsO_3 + H_2SO_4.$

NITRATES AND CHLORATES.

These salts are often used as oxidizing agents at high temperatures, since they give off oxygen on heating.

Conversion of chromic oxid into sodium chromate.

(158) $Cr_2^{iv}O_3 + 2Na_2CO_3 + \mathit{3O} = 2Na_2Cr^{vi}O_4 + 3CO_2$

(159) $KClO_3 = KCl + \mathit{3O}$

(160) $Cr_2O_3 + 2Na_2CO_3 + KClO_3 = 2Na_2CrO_4 + KCl + 3CO_2.$

Conversion of manganic oxid into sodium manganate:

(161) $Mn_2O_3 + 2Na_2CO_3 + \mathit{3O} = 2Na_2MnO_4 + 2CO_2$

(162) $3KNO_3 = 3KNO_2 + \mathit{3O}$

(163) $\left.\begin{array}{r} Mn_2O_3 + 2Na_2CO_3 \\ + 3KNO_3 \end{array}\right\} = \left\{\begin{array}{r} 2Na_2MnO_4 + 3KNO_2 \\ + 2CO_2. \end{array}\right.$

LEAD AND SODIUM DIOXIDS.

The substances are very energetic oxidizers.

Oxidation of manganous sulfate by lead dioxid and nitric acid:

(164) $2MnSO_4 + \mathit{3H_2O} + \mathit{5O} = 2HMnO_4 + \mathit{2H_2SO_4}$

(165) $5PbO_2 + 8\mathit{10}HNO_3 = \mathit{35Pb(NO_3)_2} + \mathit{25H_2O} + \mathit{5O}$

(166) $\mathit{2Pb(NO_3)_2} + \mathit{2H_2SO_4} = 2PbSO_4 + \mathit{2HNO_3}$

(167) $\left.\begin{array}{r} 2MnSO_4 + 5PbO_2 \\ + 16HNO \end{array}\right\} = \left\{\begin{array}{r} 2HMnO_4 + 3Pb(NO_3)_2 \\ + 2PbSO_4. \end{array}\right.$

Oxidation of chromic hydroxid by lead dioxid and an alkali hydroxid:

(168) $Cr_2(OH)_6 + 6KOH = \mathit{Cr_2(OK)_6} + 6H_2O$

(169) $\mathit{Cr_2(OK)_6} + \mathit{4H_2O} = 2K_2CrO_4 + \mathit{2KOH} + \mathit{6H}$

(170) $3PbO_2 + \mathit{6KOH} = 3Pb(OK)_2 + 3\mathit{H_2O} + \mathit{3O}$

(171) $\mathit{6H} + \mathit{3O} = \mathit{3H_2O}$

(172) $\left.\begin{array}{r} Cr_2(OH)_6 + 3PbO_2 \\ + 10KOH \end{array}\right\} = \left\{\begin{array}{r} 2K_2CrO_4 + 3Pb(OK)_2 \\ + 8H_2O. \end{array}\right.$

The oxidizing power of sodium dioxid may be represented by the intermediate reaction:

$$\begin{array}{ll}
(173) & \mathrm{Na_2O_2 + H_2O = 2NaOH + O.}
\end{array}$$

CHANGES IN VALENCE.

Reactions which involve changes in valence are often found difficult by the student. They can, however, usually be dissected without trouble.

Reduction of ferric chlorid by stannous chlorid:

$$\begin{array}{ll}
(174) & \mathrm{Sn''Cl_2} + \mathit{2Cl} = \mathrm{Sn_2^{iv}Cl_4} \\
(175) & \mathrm{Fe_2Cl_6 = 2FeCl_2} + \mathit{2Cl} \\ \cline{2-2}
(176) & \mathrm{Fe_2^{iv}Cl_6 + Sn''Cl_2 = 2Fe''Cl_2 + Sn^{iv}Cl_4.}
\end{array}$$

Precipitation of nickelous cyanid by chlorin:

$$\begin{array}{ll}
(177) & \mathrm{2Ni(CN)_2} + \left.\begin{matrix}\mathit{3}\mathrm{H_2O} \\ + \mathit{3O}\end{matrix}\right\} = \mathrm{Ni_2(OH)_6} + \mathit{4CN} \\
(178) & \mathit{4CN} + \mathrm{4KOH = 4KOCN} + \mathit{4H} \\
(179) & \mathit{4H + 2O = 2H_2O} \\
(180) & \mathrm{5KOH + 5Cl_2 = 5KCl + 5HCl} + \mathit{5O} \\ \cline{2-2}
(181) & \left.\begin{matrix}\mathrm{2Ni(CN)_2 + H_2O} \\ \mathrm{+ 9KOH + 5Cl_2}\end{matrix}\right\} = \left\{\begin{matrix}\mathrm{Ni_2(OH)_6 + 4KOCN} \\ \mathrm{+ 5KCl + 5HCl.}\end{matrix}\right.
\end{array}$$

Reduction of ferric salts by hydrogen sulfid:

$$\begin{array}{ll}
(182) & \mathrm{Fe_2Cl_6 = 2FeCl_2} + \mathit{2Cl} \\
(183) & \mathit{2Cl} + \mathrm{H_2S = 2HCl + S} \\ \cline{2-2}
(184) & \mathrm{Fe_2Cl_6 + H_2S = 2FeCl_2 + 2HCl + S.}
\end{array}$$

Oxidation of mercurous nitrate by nitric acid:

$$\begin{array}{ll}
(185) & \mathrm{3Hg_2(NO_3)_2 + 6HNO_3 = 6Hg(NO_3)_2} + \mathit{6H} \\
(186) & \mathrm{2HNO_3} + \mathit{6H} = \mathrm{N_2O_3 + 4H_2O} \\ \cline{2-2}
(187) & \mathrm{3Hg_2(NO_3)_2 + 8HNO_3} = \left\{\begin{matrix}\mathrm{6Hg(NO_3)_2 + N_2O_3} \\ \mathrm{+ 4H_2O.}\end{matrix}\right.
\end{array}$$

Formation of bismuth dioxid from a bismuth salt by the action of potassium stannite:

$$\begin{array}{ll}
(188) & 2BiCl_3 + \mathit{2O} = Bi_2O_2 + \mathit{6Cl} \\
(189) & Sn''(OK)_2 + \mathit{6Cl} = Sn^{iv}Cl_4 + 2KCl + \mathit{2O} \\
\hline
(190) & 2BiCl_3 + Sn''(OK)_2 = Bi_2O_2 + Sn^{iv}Cl_4 + 2KCl.
\end{array}$$

The change may be expressed graphically:

Bi	Cl	Cl Cl
Bi	Cl	Cl Cl
O	K	Sn
O	K	

Reduction of ferric salts by thiosulfates:

$$\begin{array}{ll}
(191) & Fe_2Cl_6 = 2FeCl_2 + \mathit{2Cl} \\
(192) & 2Na_2S_2O_3 + \mathit{2Cl} = Na_2S_4O_6 + 2NaCl \\
\hline
(193) & Fe_2Cl_6 + 2Na_2S_2O_3 = 2FeCl_2 + Na_2S_4O_6 + 2NaCl.
\end{array}$$

Reduction of cupric salts to cuprous iodid by alkali iodids in presence of reducing agents:

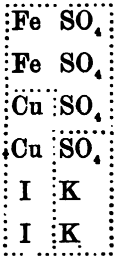
$$\begin{array}{ll}
(194) & 2CuSO_4 + 2KI = Cu_2I_2 + K_2SO_4 + (\mathit{SO_4})'' \\
(195) & (\mathit{SO_4})'' + 2KI = K_2SO_4 + I_2 \\
\hline
(196) & 2CuSO_4 + 4KI = Cu_2I_2 + 2K_2SO_4 + I_2.
\end{array}$$

In this case it is assumed that the rest, $(SO_4)''$, is set free.

Reduction of cupric sulfate in the presence of potassium iodid and ferrous sulfate:

$$\begin{array}{ll}
(197) & 2CuSO_4 + 2KI = Cu_2I_2 + K_2SO_4 + (\mathit{SO_4})'' \\
(198) & 2FeSO_4 + (\mathit{SO_4})'' = Fe_2(SO_4)_3 \\
\hline
(199) & \left.\begin{matrix} 2CuSO_4 + 2FeSO_4 \\ + 2KI \end{matrix}\right\} = \left\{\begin{matrix} Cu_2I_2 + Fe_2(SO_4)_3 \\ + K_2SO_4. \end{matrix}\right.
\end{array}$$

The graphic representation is the easier to understand:

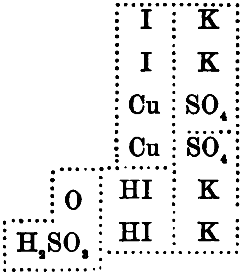


Reduction of cupric sulfate in the presence of potassium iodid and sodium sulfite:

$$2CuSO_4 + 2KI = Cu_2I_2 + K_2SO_4 + (SO_4)'' \tag{200}$$
$$(SO_4)'' + 2KI = K_2SO_4 + 2I \tag{201}$$
$$2I + H_2O = 2HI + O \tag{202}$$
$$H_2SO_3 + O = H_2SO_4 \tag{203}$$

$$\left.\begin{array}{l} 2CuSO_4 + 4KI \\ + H_2SO_3 + H_2O \end{array}\right\} = \left\{\begin{array}{r} Cu_2I_2 + 2K_2SO_4 + H_2SO_4 \\ + 2HI. \end{array}\right. \tag{204}$$

Or graphically:



Objections may be urged against the foregoing method of working out chemical equations, in effect that the student may use reactions that are impossible. Or reactions may be worked out concerning which the present state of chemical knowledge is insufficient to enable one to decide if they be correct or not. Or, again, a chemical change may be represented as progressing in several different ways, and it may be impossible to determine which one accords most fully with the facts. The same objection may be urged against the graphic method of working out reactions, a way which will always enable one to ascertain the simplest equation representing a chemical change when the substances reacting and produced are known; for it is often not clear, when there is a number of atoms of the same element present in different compounds, which of these atoms should be combined with other atoms. This is particularly the case when the reaction is complicated and involves several steps. But these very difficulties and uncertainties not only make equation-writing more interesting and of greater didactic value, but arouse in the student a desire for a fuller and more exact understanding of the problems. The equation becomes something more than a mere dry arithmetical expression of a chemical change, and indicates that in a reaction which at first glance may appear to be quite simple there is much intermediate chemical action, and that an opportunity is afforded for study and experimental investigation. In my own practice as a teacher I obtain excellent results when I ask students to write the progressive steps of a reaction in as many different ways as they can, and to determine which way is best supported by facts. Discussion is thus evoked between the men, and a recourse to the literature becomes necessary.

In a general way the following suggestions, which are not to be considered as rigid rules, may be found useful in working out reactions:

(1) Write the equation in such a way that it shows what substances are produced and demanded by the change.

(2) Write equations representing the formation of the substances demanded.

(3) Write equations representing the behavior, among themselves or with other substances, of the substances produced.

(4) Write equations representing the interaction of the various secondary products.

(5) Balance all of the equations numerically.

(6) Eliminate substances common to both sides of the equations, and add up the remaining ones.

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